THE EFFECT OF VIBRATION TRAINING ON BALANCE AND MUSCULAR PERFORMANCE WITHIN FUNCTIONALLY UNSTABLE ANKLE POPULATIONS.

By

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A Thesis submitted in partial fulfilment of the requirements of the University of Wolverhampton for the degree of Master of Philosophy

2011

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ACKNOWLEDGMENTS

I would like to pay a big thanks to all who have helped me on this journey. From the early inception with Dr Steve Day who went on to Pastures new but still remained a valuable contributor. To Professor Nevill for his help and support as an important member of my supervisory team, as well as numerous other members of the SSPAL team both academic and technical that have all provided support in their own way. A big thanks to my supervisor Dr Matt Wyon who was able to keep me focused on the bigger picture and provided me with valuable support during the process, while still maintaining a welcome sense of humour during proceedings.

Finally thanks to my family and most importantly Alice, still the best thing to have happened to me.

ABSTRACT

Ankle injuries are one of the most common injuries in sport, often leading to functional deficits and instability, a vicious cycle of recurrent sprains and time loss due to injury. Although research has been conducted on the best methods of treating such deficits and instability, new training methodologies are continually being sought to help improve clinical outcomes and with this comes a need for designed research to test such hypotheses.

The purpose of the present research was to investigate the effect of vibration training on balance and muscle function in physically active individuals suffering self reported functional ankle instability (FAI). Stage one of the research was to initially investigate the effect of a six week whole body vibration training (WBVT) exercise routine on 38 University dancers reporting FAI. An initial assessment of the severity of the instability was done using the Cumberland Ankle Instability Tool (CAIT), to identify those who classed themselves functionally unstable but still able to participate in their chosen sport. The group was randomly arranged into one of two groups (treatment and control) and a pre/post test study was undertaken, with the control group asked to continue normal activity. The selection of participants was based on instability score from the CAIT. A larger sample of athletes was initially recruited across two accessible sports of football and dance due to access and availability. These groups then completed CAIT and where included if scoring criteria were met.

The treatment group undertook six weeks of progressive vibration training on a stabile vibration system. Pre and post testing consisted of measures of static single leg balance, a Star Excursion Balance Test (SEBT) and Electromyography (EMG) of peroneus longus in demi-pointe. Results indicated a significant improvement in static balance ($p = .04$) and certain SEBT directions within the treatment group compared to the control group ($p < .05$). Neither group reported any significant difference in mean power frequency for the peroneus longus ($p > .05$). The results of the study suggested six weeks vibration training improved certain balance parameters within FAI populations. These results although initially encouraging, identified the need for further research with not just a direct comparison between treatment and control, but a closer examination of the effect of vibration training in comparison to more classical methods of rehabilitation before it can be recommended as a serious methods of treatment for FAI.

The second stage of the research involved the implementation of a new piece of rehabilitation equipment which combined a vibration unit within a wobble board (Vibrosphere TM, Sweden). The manufactures claim the combination of the two principles accelerates rehabilitation for numerous lower body injuries and disorders. This specially designed unit allowed direct analysis of the effect of the vibration component of the unit on balance and muscle function, by comparing those who used the combined vibration/wobble board and those who simply used the wobble board alone. A control group was also included to analyse any difference over time as the testing was done during a pre-season training cycle. The research consisted of 33 semi-professional footballers reporting FAI as confirmed by CAIT and taler tilt and an anterior drawer test, being randomly assigned to one of three groups; Vibration/wobble board, Wobble board alone and Control. Both Vibration/wobble

board and Wobble board alone completed identical exercises on identical equipment so results could not be attributed to different equipment.

The results of the study suggest a significant difference in static balance; modified SEBT and Single leg triple hop for distance between groups with the greatest improvement being within the combined vibration/wobble board group ($p < .05$). The results suggest the combination of vibration and wobble board improve balance and functional strength in those footballers reporting FAI compared to wobble board training alone.

The precise mechanisms behind the current results are unclear. It has been suggested that it may be due to vibration having a positive effect on the stimulation of mechanoreceptors and the combination of that and unstable surface control seems to be optimal. It is difficult to compare studies but the research has highlighted certain areas for further research. The difference in static balance and SEBT scores between the dancers and footballers seems to suggest that the CAIT scores although similar may identify the need for more specific tests for each population. Also a longitudinal study is required to access injury rates following intervention and effect duration of the improvements seen.

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CHAPTER ONE – INTRODUCTION

Ankle sprains are the most common injury sustained in sport, which often lead to chronic pain, swelling and a high reoccurrence of injury (Holmes and Delahunt 2009). It has been reported that recurrence rates following ankle sprains, in particular the more common lateral ankle sprain, are five times greater then in those individuals with a history of previous ankle injury (McKay *et al.* 2001), leading to substantial loss in playing time, pain, and psychological distress (McCarthy *et al.* 2003). In fact, one of the goals of the World Health Organization (WHO) to be achieved within the twentieth century, was to substantially reduce the incidence and severity of sports injuries (Wedderkopp *et al.* 1999). The term functional ankle instability (FAI) describes the subjective feeling of the ankle "giving way", and was first conceptualised by Freeman (1965). The basic premise underlying the articular differentiation theory of functional instability originally developed by Freeman (1965) was that damage to the ankle joint capsule and ligaments produced delayed and diminished reflex responses in the ankle joint muscular structure. Following injury, the subject is unable to adjust unexpected perturbation to the ankle through sports or daily activities rendering the ankle joint vulnerable to repeated inversion injury (Holmes and Delahunt 2009).

The criterion for defining functional ankle instability varies greatly within the literature making it difficult to compare research and exact injury mechanics (Hubbard and Kaminski 2002). This is due to the varying opinion on what constitutes FAI (someone's defined by the clinicians' previous experience or success with using certain parameters in their clinics). Also the availability of expensive equipment (i.e. MRI) to discount mechanical instability plays a role in the classifying of criteria.

The Cumberland ankle instability tool (CAIT) is structured so that the feeling of instability is reported for different types of activities such as running, walking, hopping, and descending stairs (Hiller *et al.* 2006), all items applicable to competitive athletes. The nine items generate a total score from 0 to 30 for each foot, in which 0 is the worst possible score, meaning severe instability, and 30 is the best possible score, meaning normal stability (Hiller *et al.* 2006). The CAIT is a reliable (ICC = 0.96) instrument that can discriminate stable from unstable ankles and measure the severity of functional ankle instability (Hiller *et al.* 2006). Concurrent validity was established by comparison with the Lower Extremity Functional Scale (LEFS) and a visual analog scale (VAS) of global perception of ankle instability by using the Spearman ρ. Construct validity and internal reliability with Rasch analysis using goodness-of-fit statistics for items and subjects separation of subjects, correlation of items to the total scale, and a Cronbach α equivalent (Hiller *et al.* 2006).

Lynch and Renstrom (1999) reports the lateral ligamentous complex of the ankle is composed of three ligaments: (i) the anterior talofibular ligament (ATFL); (ii) the calcaneofibular ligament (CFL); and (iii) the posterior talofibular ligament (PTFL) [Figure. 1].

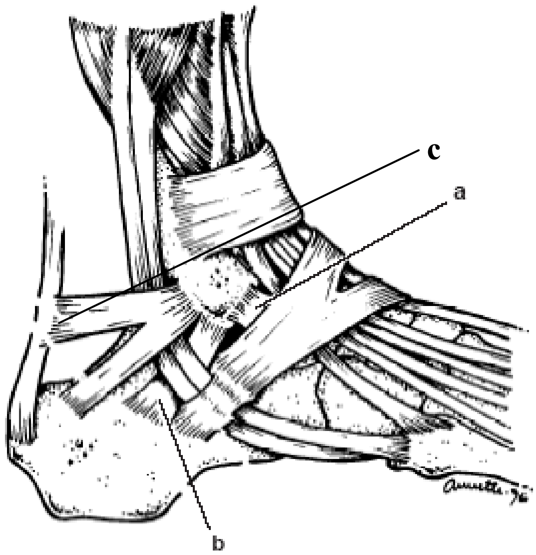

Figure 1. Lateral View of the ligaments of the subtalar region of the ankle: (a) anterior talofibular ligament; (b) calcaneofibular ligament and (c) the posterior talofibular ligament (Lynch and Renstrom 1999).

Ligaments of the ankle serve three major functions; first they provide proprioceptive information for joint function, as the ligaments are richly innervated with proprioceptive end organs (Safran *et al.* 1999a). Secondly ligaments contribute to stability of joint motion, thereby reducing excessive motion; and thirdly, ankle ligaments act as a guide to direct lines of motion (Safran *et al.* 1999a).

The ATFL runs parallel to the axis of the neutral foot, however when the foot is plantar flexed it assumes a position parallel to the axis of the leg (Balduini and Tetzlaff 1982). Injury to the CFL and PTFL are as a result of sizeable trauma to the ATFL, as isolated injuries to these two structures are rare due to their anatomical positioning on the ankle joint (Lynch and Renstrom 1999). In the neutral position the ankle joint is stabilised by the shape of the talus and the mechanically stable fit of the tibia and fibula (Lynch and Renstrom 1999). Stability is further enhanced by weight-bearing compression loads, which result in 100% of inversion stability (Stormont *et al.* 1985). Thus when the foot is planter flexed and hyper-supinated, with excessive inversion and internal rotation the ATFL is the first ligament to be damaged [Figure 1.1]. If the excessive tearing force continues the CFL is injured followed by the PTFL (Lynch and Renstrom 1999). Tropp *et al*. (1985) suggests this type of inversion trauma is primarily due to the ankle going through a transition from unloaded to loaded. If the ankle has been forced past a certain point of rotational mal-alignment, the transition to a loaded condition provokes increased subtalar inversion torque, leading to injury (Tropp *et al.* 1985).

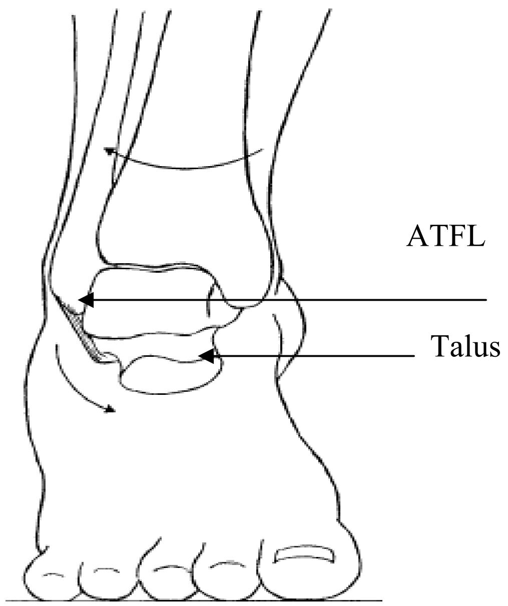

Figure 1.1 Illustrates the development of tension within the ATFL as the leg externally rotates in relation to foot, which resists rotary subluxation of the talus during a plantar flexed movement. This could be a result of touchdown or a cutting movement (Wilkerson 2002).

1.1 Clinical importance of balance and proprioception

In any situation there are gravity, inertia, and forces creating a specific external load on muscular structures (Ergen and Ulkar 2008). Internal forces are therefore required to balance theses forces, well developed balance and proprioception allows the body to overcome any overload on structures such as the ankle and allows the maintenance of dynamic joint stability (Tropp *et al.* 1992). In essence this dynamic stability is the by product of the proprioceptive system, and with this comes the risk of partial damage through injury or distribution mechanoreceptors which can lead to balance and proprioception deficits (Palmieri-Smith *et al.* 2009). Consequently, re-injury becomes a real risk due to the decrease in neural feedback from the injured ankle (Lephart *et al.* 1998). The effect of ligamentanous injury to the ankle resulting in functional instability may lead to further micro trauma and re-injury due to substantial distribution to the afferent pathway mediated by joint mechanoreceptors and spinal reflex pathways (Lephart *et al.* 1998). These factors can initiate a vicious cycle of injury and re-injury not only disturbing performance and training but may lead to problems in daily living activities if left untreated (Ergen and Ulkar 2008)

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Aston-Miller *et al*. (2001) conclude that spindle output presents the only source of proprioceptive information that is modifiable through training. Proprioception has been thought to be improved when muscles are well conditioned around the joint increasing gamma-system neural firing rates (Gandevia *et al*., 1992; Lephart *et al*., 1996; Aydin *et al*., 2002). An increase in muscle spindle activity, coupled with increased firing rate of gamma neurons has been shown to increase precision of proprioceptive information (Kakuda *et al*. 1997). The importance of muscle input at the ankle has been further substantiated by the findings that even when the muscle is relaxed, proprioceptive accuracy can be increased fivefold by stretching the plantar flexor muscles to stimulate neuron enriched muscle spindles (Refshauge and Fitzpatrick 1995). Thus, it could be argued from the current findings that any loss in proprioceptive input from the joint and ligamentous receptors is compensated for by improvements in muscle afferents efficacy as suggested by Refshauge *et al*. (2000).

1.2 Rehabilitation methods and Vibration

Strength deficits especially those of the peroneus muscles was first identified as a significant factor contributing to recurrent ankle sprains by Bosien *et al*. (1955). Uh *et al*. (2000) suggested single leg strength training programs for untrained ankles improved peak torque values in muscles surrounding the ankle. The untrained ankles where used to replicate extended periods of immobilisation often associated with ankle injury which adversely affect strength in the ankle muscles (Uh *et al.* 2000). A serious problem with many of the studies that have shown contralateral strength gains is that they compare strength increases in trained and untrained limbs of subjects undergoing training. However the alternative is to recruit participants at the exact point of injury which is rare.

With this design, improvements in strength in comparison to untrained limb may be more due to familiarity with testing procedure then training regime (Munn *et al.* 2004). Powers *et al*. (2004) reports muscle fatigue can significantly impair ankle proprioception and balance, thus improvements in endurance and functional strength in muscles surrounding the ankle joint due to training could improve stability and muscle proprioception. Research has taken this theory further by identifying not only strength but postural control, proprioception and neuromuscular control as key factors that not only can effect ankle injury risk (Hertel 2002; Hiller *et al.* 2004; Mitchell *et al.* 2008a, b; Arnold *et al.* 2009; Ross *et al.* 2009a; Sefton *et al.* 2009; Suda *et al.* 2009); but also provide Clinician and Coaches with parameters that can be measured and manipulated by rehabilitative intervention (Holmes and Delahunt 2009). Degenerative and joint capsule changes to the ankle are not easily treated/assessed using conservative methods (Hertel 2002) and therefore have limited real world application.

Rehabilitation of athletic ankle injuries requires the prescription of sport-specific exercise and activities that challenge the recovering tendons, ligaments, bones, and muscle fibres without overstressing them (Mattacola and Dwyer 2002). Wobble board training and specific strength exercises in combination has been shown to be the optimal approach in allowing return to activity as well as single leg rehabilitation work improving strength in the uninjured leg due to the crossover effect (Zoch *et al.* 2003). The crossover effect has been identified by other researchers throughout different joints in the body (Kannus *et al.* 1992; Uh *et al.* 2000; Munn *et al.* 2004); The premise of this phenomenon being exercise on one limb causes increase strength and function in the contrlateral unexercised limb (Munn *et al.* 2004). The goal however of ankle rehabilitation has not altered for clinicians and is still to return the athlete to full functional fitness as soon as possible (Safran *et al.* 1999b). New training methodologies are continuing to be investigated to identify their effectiveness and ease of application.

Whole-body vibration training has gained much consideration and has been used widely in numerous settings both sporting and clinical (Bosco *et al.* 1999a; Bosco *et al.* 1999b; Cardinale 2002; Rehn *et al.* 2007). The central argument for using vibration for muscle training has been based on the assumption that strength and power improvements can be easily achieved during a 4-6 week period (Cardinale and Bosco 2003). More and more scientific publications report various positive effects from vibration training in particular among older populations looking to improve balance and decrease fall risk for a better quality of life (Bruyere *et al.* 2005; Bogaerts *et al.* 2007; Rees *et al.* 2009; Trans *et al.* 2009). Protection of the joint during functional activity requires mechanical and dynamic restraint (Hertel 2002), the mechanical restraints (ligiments, articular tissue) need the contribution of the dynamic restraints (musculotendinous unit, mechanoreceptors, visual organs, somatosensorial receptors) (Ergen and Ulkar 2008; Hopkins *et al.* 2008). Vibration training may help improve this dynamic restraint capacity.

1.3 Rationale for Study of Problem

As it has been suggested that WBV increases muscle spindle sensitivity and function (Rittweger *et al.* 2003; Hopkins *et al.* 2008), a significant increase in muscle spindle sensitivity , potentially induced by WBV would enhance overall dynamic restraint (Hopkins *et al.* 2008). Based on the theory that damaged muscle/joint receptors are, in part, responsible for poor balance and disrupted proprioception in FAI ankles, various studies have investigated influencing this by providing rehabilitation methods to improve afferent feedback at the ankle and foot.

However, the application of vibration therapy has yet to be used within a functionally unstable population who are continuing to perform their chosen sport. This is partly due to the cost associated with such equipment and the available funds to attain enough devices for a large squad of players ((Marín and Rhea 2010) and the perceived possible danger from vibration exposure (Mester *et al.* 1999). Static measures of COP, although capable of identifying balance deficits (Arnold *et al.* 2009), are inherently incapable of adequately representing lower-extremity function for active movements that are commonly problematic in those with FAI (Ross *et al.* 2009b) . Therefore a Dynamic balance test in conjunction with static balance parameters has been suggested as a more appropriate testing method in FAI subjects, as it more closely represents lower extremity function during activity. Also muscle function tests need to stress the importance of functional strength and performance improvements pre and post vibration intervention.

1.4 Statement of Purpose

The purpose of this research study was to investigate the effects of stable and unstable vibration training on balance and functional strength performance in FAI subjects.

Study 1

Hypothesis H1 Centre of pressure (COP) single leg balance, Peroneus longus Electromyography (EMG) mean power frequency and STAR excursion balance test within FAI dancers will significantly differ between those participating in 6 weeks whole body vibration training and those not participating in vibration training.

Null hypothesis H2 COP single leg balance, Peroneus longus EMG mean power frequency and STAR excursion balance test within FAI dancers will not significantly differ between those participating in 6 weeks whole body vibration training and those not participating in vibration.

Study 2

Hypothesis H1 COP single leg balance, Star excursion balance test and Triple hop test within FAI footballers will significantly differ between those participating in balance vibration training on the Vibrosphere ™ and those completing balance training in the absence of vibration over a six week period.

Hypothesis H1 COP single leg balance, Star excursion balance test and Triple hop test within FAI footballers will not significantly differ between those participating in balance vibration training on the Vibrosphere ™ and those completing balance training in the absence of vibration over a six week period.

1.5 Delimitations

- All subjects where given the same rehabilitation programme in both studies.
- Testing was conducted at different times of the day.
- Researchers assumed all participants where honest through the duration of training.
- No orthopaedic surgeon was present to distinguish those individuals that may have associated mechanical deficiencies of the ankle.
- Only injured leg was tested. Thus, all comparisons were limited to the injured limb.

1.6 Limitations

- Subjects following the training program for full duration.
- Subjects answering CAIT questionnaire honestly.
- Motivation levels of subjects during testing and training.
- Accuracy of EMG and RS scan.
- Results may not be generalized to populations other than active college-aged dancers and soccer athletes.
- No direct comparison between stable and unstable vibration training equipment.
- Statistical power calculations where not performed prior to recruitment

1.7 Definition of Terms

Ankle sprains- An articular injury in which some fibres of the ankle ligaments are damaged but the mechanical continuity remains sound. Typically self reported.

Closed kinetic chain exercise- Are performed where the foot is fixed and cannot move. The foot remains in constant contact with the surface, usually the ground or the base of a machine. These exercises are typically weight bearing exercises.

Dorsiflexion- Motion bringing the top of the foot towards the lower leg.

Eversion- Rotation away from the midline of the body.

Functional ankle instability (FAI) - Characterized by a history of insecurity and subjective feeling of giving way at the ankle during activity in the absence of any mechanical damage. Symptoms include poor joint position sense, postural control, nerve conduction and strength deficits.

Ground reaction force- Impact forces sustained on the body from a combination of body weight and gait speed in accordance with Newton's third law of motion.

Inversion- Rotation towards the midline of the body.

Ligaments- A ligament is a short band of tough, fibrous connective tissue composed mainly of long, stringy collagen fibres. Ligaments connect bones to other bones to form a joint. They act as mechanical reinforcements with extra-capsular ligaments join bones together and provide joint stability.

Mechanical ankle instability- Laxity of the ankle resulting from structural impairment due to severe damage to ligamentous tissue that supports the joint. Often requires surgery to treat successfully.

Muscle mechanoreceptor- Mechanoreceptors are the sensory receptors that respond to mechanical pressure or distortion (ie. muscle spindles).

Open kinetic chain exercises- These exercises are performed typically were the foot is free to move. These exercises are characteristically non-weight bearing.

Peroneal muscle group- Consisting of the peroneus longus muscle, orientation is lateral and originate at the head of the fibula and insert at the medial cuneiform and first metatarsal. The peroneus brevis is inferior in origin to the fibula and insertion is at the fifth metatarsal. Both muscles provide stability to the ankle and planter flexion, eversion action. The third peroneal muscle, the peroneus tertius has a similar function as the peroneus brevis.

Plantar flexion- Motion extending the top of the foot away from the lower leg (i.e. pointing of toe).

Postural control- Subjects ability to retain balance, usually during single leg stance; this requires acquisition of information via proprioceptive and visual cues, followed by correct execution to information by the musculoskeletal system.

Proprioception- The sense of the position of parts of the body, relative to other neighbouring parts. Proprioception is a sense that provides feedback solely on the status of the body internally.

Range of motion- Joint flexibility is defined as the range of motion (ROM) allowed at a joint. A joint's ROM is usually measured by the number of degrees from the starting position of a segment to its position at the end of its full range of the movement.

Subtalar joint- The subtalar joint, also known as the talocalcaneal joint, is one of two joints in the ankle. It occurs at the meeting point of the talus and the calcaneus, two bones in the ankle. The joint allows inversion (a combination of adduction and plantar flexion) and eversion (a combination of abduction and dorsiflexion).

Volume- Quantity of training or sum of work performed during a training session.

Wobble board- Also sometimes called a balance board is a circular platform with a hemispherical ball underneath on which subjects stand and use ankle strategy to maintain balance.

Vibrosphere- A portable Vibrating wobble board which can be manipulated by changing vibration frequency (Hz) or stability mat.

Somatosensory- is a diverse sensory system comprising the receptors and processing centers to produce the sensory modalities such as touch, temperature, proprioception.

Hertz- A unit of frequency, defined as the number of complete cycles per second.

Whole Body Vibration (WBV)- A neuromuscular training method where a participant stands on a specially designed platform and frequency and durations are manipulated to provide stimulus that is transmitted to the body.

CHAPTER TWO – LITERATURE REVIEW

2.1 Mechanics of ankle injury

Given the numerous bones, ligaments, and articulations the ankle is arguably the human body's most complex area (Whiting and Zernicke 1998). It is hypothesised that ankle injuries encapsulate one of the most common sporting injuries (Papadopoulos *et al.* 2005). Epidemiological studies have shown that 10-28% of all sports injuries are ankle related (Garrick 1977; Yeung *et al.* 1994; Fong *et al.* 2007a), with up to 75% of the all ankle injuries are sprains (Garrick and Requa 1988) and 85% these sprains are caused by inversion trauma (Baumhauer *et al.* 1995).

Although epidemiological studies for the purpose of this research provide substantial evidence for the high incidence of lateral ankle sprains, the author acknowledges that the precise incidence of ankle sprains in any population is not known (Robbins and Waked 1998). Robbins and Waked (1998) suggest that such data obtained by epidemiological studies represent medical consultation frequency rather then ankle sprain frequency. Those who sustain ankle sprains, especially those that are of a recurrent nature, are unlikely to seek medical attention as most sprains are not considered severe enough (Robbins and Waked 1998).

In acknowledging these limitations, it should be noted that the issue of ankle injury, regardless of methodological issues, is problematic among athletic populations leading to up to 12 months absence from sport (Kofotolis *et al.* 2007) and potential chronic pain or disability (Beynnon *et al.* 2002). Gross and Marti (1999) further emphasise the importance of the prevention of ankle sprains among susceptible athletic populations; their study amongst elite volleyball players indicated an increased risk of osteoarthritis and articular degeneration of the ankle joint due to repeated trauma.

2.2 Common causes of ankle injury

Landing on an irregular surface or poorly executing a cutting movement can result in poor foot positioning and therefore increased supination torque overloading, subsequently leading to injury of the lateral ankle ligaments (Wright *et al.* 2000). Andersen *et al.* (2004) identified that the main mechanism for ankle injury during a Norwegian elite football season, was due to laterally directed force from player to player contact. However it was noted that the collision itself did not produce the injury, but the proceeding poor foot positioning and proprioceptive control that followed on landing (Andersen *et al.* 2004) . Andersen *et al.* (2004) discuss how this type of ankle injury is particularly prevalent in those individuals with a history of ankle problems as they lack the relative neuromuscular ability to resist such damaging forces applied to them through contact either by a player or by the subsequent poor postural control on landing. Wright *et al.* (2000) suggests that poor foot positioning on touchdown, such as excessive plantar flexion and inversion, increases ground reaction force moment arm around the subtalar joint which may increase the incidence of injury to the ankle [Figure 2].

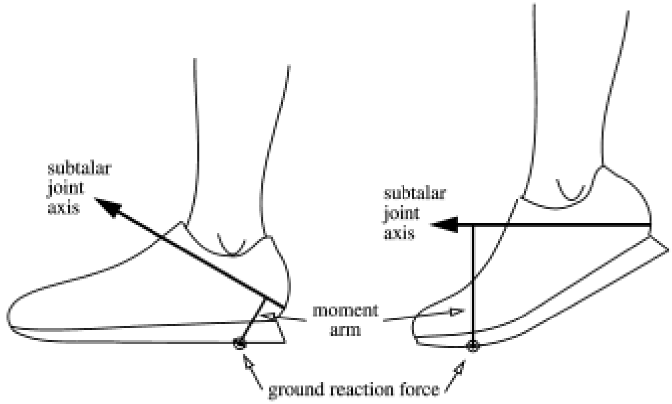

Figure 2 A view of the foot at the sagital plain of touchdown. The moment arm of the horizontal component of the ground reaction force about the subtalar joint is much greater when contact is made with the toe (right), compared to the heel (left) (Wright *et al.* 2000)

A history of ankle injury indicates an individual's higher susceptibility to suffer a subsequent sprain compared to others; Stasinopoulos (2004) indicated that female volleyball players who had a history of four or more previous sprains to the same ankle were more likely to have further ankle sprains regardless of any traditional preventative rehabilitation methods used during the course of a season. This was in comparison to the team mates who had suffered three or less sprains (Stasinopoulos 2004). The causes of such recurrent sprains have been reported as due to inappropriate foot positioning prior to touchdown due to functional deficits in balance, functional strength and proprioception among susceptible populations (Munn *et al.* 2009). Wright *et al.* (2000) hypothesises that such poor foot positioning and postural control is the fundamental cause of ankle sprains. Such susceptibility has been reported by researchers in the past amongst individuals with a history of recurrent ankle injury (Safran *et al.* 1999a; Konradsen and Magnusson 2000; Refshauge *et al.* 2000; Bahr and Krosshaug 2005; Arnold *et al.* 2009; Munn *et al.* 2009; Oztekin *et al.* 2009; Sefton *et al.* 2009).

2.3 Functional ankle instability and associated deficiencies

Rehabilitation of the ankle is a vital part of any treatment plan, especially in those individuals with a chronic condition such as functional ankle instability (Conti and Stone 1998). In patients with such persistent problems, after initial conservative or functional therapy there still persists muscle weakness and frequent giving way (Lynch and Renstrom 1999). Many of these problems are associated with ankle instability, it is however important to distinguish between the two types of ankle instability - mechanical and functional. Mechanical instability refers to abnormal laxity of the ligamentous structure, and functional instability refers to normal ligamentous structure but abnormal function, with recurrent episodes of the ankle giving way (Lynch and Renstrom 1999).

Although the precise reasoning behind recurrent ankle injury is unknown (Safran *et al.* 1999a); Freeman (1965) was the first researcher to recognise functional ankle instability. Freeman (1965) reported that 40% of his patients complaining of chronic ankle sprains, suffered from a loss of proprioception and subjective feeling of the ankle 'giving way' . Functional ankle instability is a subjective complaint of instability in the absence of any mechanical distribution or damage (Madras and Barr 2003). Self-report questionnaires are an important part of both clinical practice and research because they can combine efficiency with good reliability and low cost (De Noronha *et al.* 2008). Recently, two questionnaires for assessment of one of the consequences of ankle sprain, that is functional ankle instability, were developed: the Ankle Instability Instrument (AII) (Docherty *et al.* 2006) and the Cumberland Ankle Instability Tool (CAIT, see Appendix) (Hiller *et al.* 2006). Both questionnaires have been reported as reliable, CAIT reported excellent test re test reliability (ICC (2,1) =.96) and the AII also produced similar test re test reliability scores (ICC (2,1) = .95)(Docherty *et al.* 2006; Hiller *et al.* 2006). However the Cumberland Ankle Instability has been extensively researched within competitive sporting populations and also has considerably more reliability across populations and cultures (De Noronha *et al.* 2008).

The ligaments, tendons and muscles of the ankle joint have been reported as extensively innervated by mechanoreceptors (Takebayashi *et al.* 1997). Type I/II articular mechanoreceptors originating in the joint capsule consisting of 2-4 and multiple corpuscles serve as a range limiting detector, providing extreme range of motion protection to the ankle joint by signalling the presence of extreme adverse stimuli at the joint (Michelson and Hutchins 1995; Lephart *et al.* 1998). A disruption due to injury in the sensory receptors within the ligamentous structure of the ankle joint results in decreased ability to detect changes in joint position and postural control (Michelson and Hutchins 1995; Hertel 2000; Arnold *et al.* 2009; Munn *et al.* 2009). Figure 2.1 depicts the progression of functional instability due the interaction between joint instability and decreased neuromuscular control (Lephart and Henry 1996).

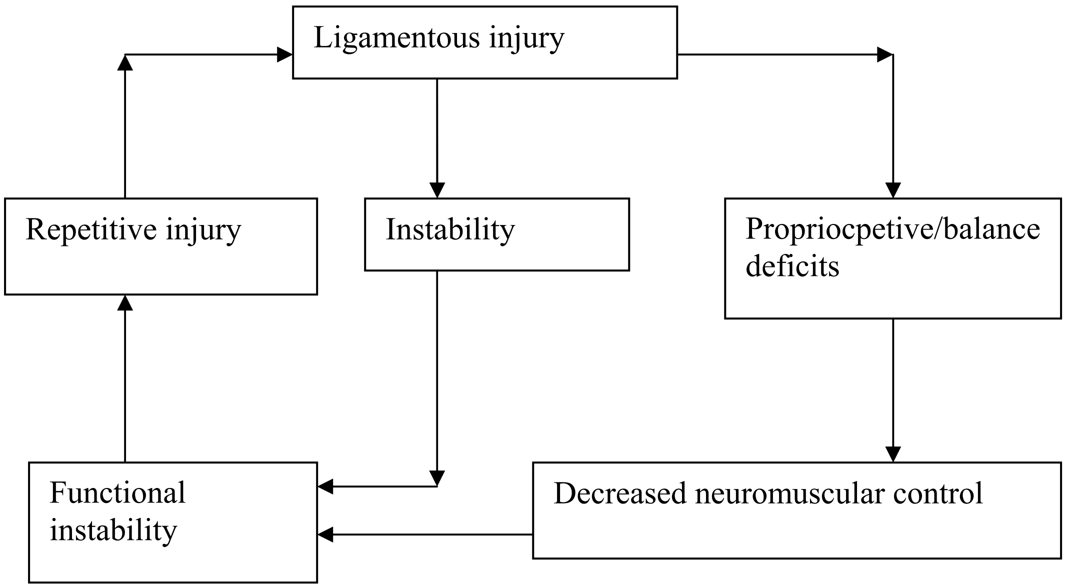

Figure 2.1 Functional instability paradigm (Lephart and Henry 1996).

Muscle receptors also provide a necessary complementary neural contribution in addition to information provided by ligaments and joint capsules (Lephart *et al.* 1998; Ribot-Ciscar *et al.* 2003). Muscle spindles located within skeletal muscle, maintain a systematic relationship with articular mechanoreceptors to provide information to the central nervous system on joint motion, acceleration and position (Lephart *et al.* 1998; Ribot-Ciscar *et al.* 2003). The muscle spindle itself has been recognised as one of the afferent nerves that are potentially modifiable through training (Hubbard 2005). Proprioceptive and balance exercises have been shown to increase the sensitivity of the peroneal muscles to inversion signals from the ankle (Javed *et al.* 1999). Poor conditioning of the muscles which invert and pronate the complex ankle joint have been recognised as a contributing factor to functional instability following lateral ankle sprains (Konradsen *et al.* 1997; Powers *et al.* 2004). Thus, it is likely a well structured rehabilitation programme improving muscle strength and endurance may improve stability (Powers *et al.* 2004).

Kaminski *et al* (2003) recognise that the exact reasoning behind functional strength deficits of the ankle and the increased predisposition to future ankle injury is still unknown. One possible reason behind such susceptibility following ankle injury is incomplete or inappropriate rehabilitation which leads to improper motor neuron recruitment and motor neuron firing patterns during inversion trauma (Docherty *et al.* 1998; Holmes and Delahunt 2009). Muscle and tendon vibrations induced through movement indicate that muscle mechanoreceptors may regain increased sensitivity of joint position sense only after appropriate rehabilitation training (Docherty *et al.* 1998; Holmes and Delahunt 2009). Other studies have also recognised a vital link between strength gains leading to enhanced proprioception (Tropp 1986; Wiksten *et al.* 1996; Sekir *et al.* 2008b; Holmes and Delahunt 2009). This reclamation of sensitivity of the peroneal muscle mechanoreceptors to inversion stimulation has also been indicated by Javed *et al* (1999). Re-education of the peroneal muscles has been shown through strength and proprioception training to effectively prevent the associated deficiencies of functional ankle instability in functionally unstable populations (Javed *et al.* 1999).

2.4 Classical strength and proprioception rehabilitation

Functional strength and proprioceptive training has classically been reported as the key rehabilitation method for reducing postural sway, increasing balance and improving peroneal muscle strength (Konradsen 2002a; Lee and Lin 2008; Holmes and Delahunt 2009). Willems *et al.* (2002) suggest that the possible cause of recurrent ankle sprains is a combination of diminished proprioception and muscle weakness around the ankle joint. Munn *et al.* (2009) meta-analysis has identified balance and postural control as the main sensormimotor deficits associated with FAI. These results lead the researchers to identify ankle injury prevention within functionally unstable groups should encapsulate the importance of both proprioceptive balance exercises as well as functional strength exercises that provide sufficient intensity to replicate the demand placed on the joint during injury (Munn *et al.* 2009). Such exercises may effectively improve balance and strength , and break the vicious cycle of recurrent ankle sprains among susceptible populations (Willems *et al.* 2002).

Functional strength training has typically been a major element in rehabilitation programmes following ankle sprains and is most often initiated once pain-free range of motion is regained (Kaminski and Hartsell 2002). The ankle joint musculature plays an integral role in dynamic stabilization of the ankle joint, which is achieved by co-contraction of the musculature surrounding the joint (Kaminski and Hartsell 2002). Defining functional strength in FAI populations ranges from as diverse scope of inversion/eversion ratio, to the ability to maintain balance on landing, to as simple as maintaining quiet stance (Holmes and Delahunt 2009). No one definition is agreed as optimal, just as no one treatment protocol is.

Wobble board training has been reported as one of the most effective and popular methods of proprioceptive training for individuals suffering from functional ankle instability (Madras and Barr 2003). The view is that peroneal muscle groups and mechanoreceptors of the ligament and tendon structures of the ankle can make more precise judgements of the position of the ankle through re-education of what constitutes negative stimuli (Javed *et al.* 1999). Therefore, proprioceptive training preserves the stimuli recognition and enhances coordination of the complex ankle structure (Javed *et al.* 1999).

Prospective research has suggested that proprioceptive wobble board training can significantly reduce ankle injury compared to control groups that have not undertaken any wobble board training (Verhagen *et al.* 2004). However it should be noted that this research was performed as a preventative method for female volleyball players who had no previous ankle instability, so comparisons to an unstable population are difficult. Waddington and Adams (2004) also support the effectiveness of wobble board training on the improvement of ankle joint position sense and thus reduction in recurrent injuries. Five-weeks of wobble board training resulted in significant (P<0.003) improvements in ankle joint position sense, compared to control groups (Waddington and Adams 2004). However some researchers have questioned whether wobble board training alone has the functional capacity to develop a rehabilitation programme that meets the individual needs of each athlete (Mattacola and Dwyer 2002). A common mistake when performing proprioception and balance exercises is the lack of controlled variability in speed and intensity (Mattacola and Dwyer 2002).

Although there are numerous functional strength and proprioceptive rehabilitation exercises, ranging in time commitment, equipment and intensity (Mattacola and Dwyer 2002; Madras and Barr 2003; Powers *et al.* 2004; Sekir *et al.* 2008b), Blackburn *et al.* (2000) analysis of key clinical studies in ankle instability points out that no single training program is more superior then another for the enhancement of strength and proprioception of the ankle. Although it is important to individualise each rehabilitation program, a simple well structured rehabilitation program is more realistically the one which will be incorporated by physicians and coaches (Blackburn *et al.* 2000). Research involving a combination of strength and proprioception training within functionally unstable populations requires further investigation (Salavati *et al.* 2009).

2.5 Whole body vibration training

Vibration is a mechanical stimulus characterised by an oscillatory motion. The biomechanical variables that determine its intensity are the frequency and amplitude. The repetition rate of the cycles of oscillation determines the frequency of the vibration (measured in Hz) (Cardinale *et al.* 2005). Vibration has been studied extensively for its dangerous effects on humans at specific amplitudes and frequencies (Adamo *et al.* 2002; Yamada 2002; Matloub *et al.* 2005). On the other hand, recent work has suggested that low amplitude, low frequency mechanical stimulation of the human body is a safe and effective way to exercise musculoskeletal structures. In fact, increases in muscular strength, power and function have been seen in humans exercising with vibration platforms (Bosco *et al.* 1999a; Bosco *et al.* 1999b; Mester *et* *al.* 2006; Nordlund and Thorstensson 2007; Rehn *et al.* 2007; Savelberg *et al.* 2007; Trans *et al.* 2009).

Training exercises during vibration interventions are one way to manipulate load, such as single or double legged tasks. (Cochrane and Stannard 2005a). Also hertz and time progression can be altered to provide progressive overload (Van Nes et al. 2006). Rittwegar (2010) identifies time under tension or time under exposure as key to progressive overload. Vibration is a mechanical oscillation, i.e. a periodic alteration of force, acceleration and displacement over time. Vibration exercise, in a physical sense, is a forced oscillation, where energy is transferred from an actuator (i.e. the vibration device) to a resonator (i.e. the human body, or parts of it) (Rittweger 2010). The longer exposure to this or the increase in hertz (to increase displacement of the body and acceleration due to gravity), the more stress is placed on the body to maintain correct stance and muscle length as well as dampen oscillations to prevent injury (Rittweger 2010).

It has been suggested that muscle stimulation by vibration may induce improvements in the mechanical power of the lower limbs in elite athletes through neural adaptation (Bosco *et al.* 1999a). Vibration exercises impose hyper gravity due to high acceleration loads (Torvinen *et al.* 2002b), these loads added to the mechanical action of the vibration produce fast and short changes in the length of the muscle tendon complex (Cardinale and Bosco 2003). This vibration is detected by higher sensory receptors which control passive tension and attempt to dampen the vibratory waves through reflex activity , this effect is known as Tonic Vibration Reflex (Cardinale and Bosco 2003) [Figure 2.2].

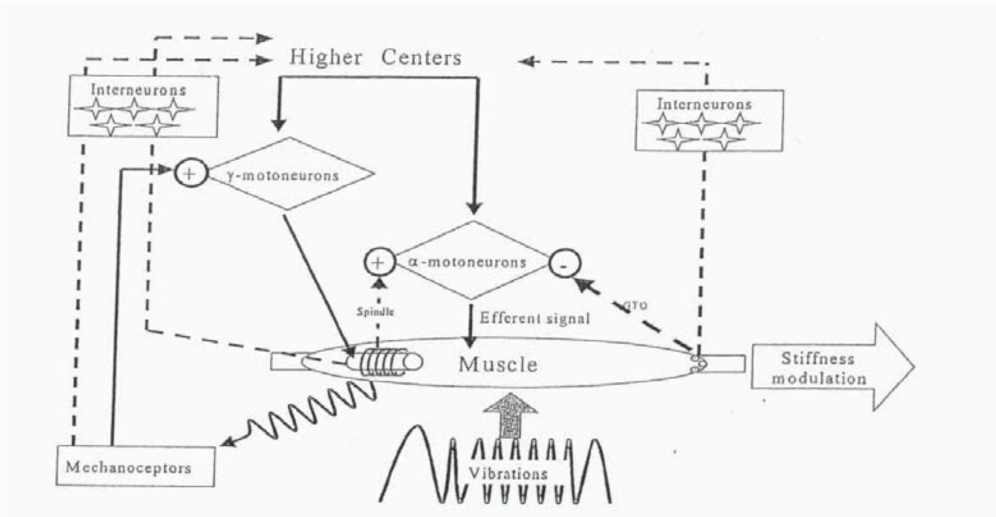

Figure 2.2 Vibration activity at the muscle being picked up by mechanoreceptors and then sent to higher brain centres for a protective response to be initiated in the way of tonic vibration reflex (Cardinale and Bosco 2003).

However the theory of Tonic Vibration Reflex is largely debated by Nordlund and Thorstensson (2007). Their meta analysis on the strength training effects of vibration highlight the link between empirical research (Brown *et al.* 1967) and the theory of Tonic Vibration research as tenuous and needs further investigation and discussion (Nordlund and Thorstensson 2007). However the scope of their review does recognise that the effects of WBV on clinical/rehabilitation populations is inconclusive, and the effect vibration may have on other selected variables such as balance, proprioception and flexibility needs further research (Nordlund and Thorstensson 2007).

Whole body vibration (WBV) exercise have been shown to increase muscle strength with several studies showing that WBV is a time-saving, safe and effective intervention for reducing the decline in muscle strength and functional capacity associated with injury (Bosco *et al.* 1999a; Bosco *et al.* 1999b; Mester *et al.* 2006; Nordlund and Thorstensson 2007; Rehn *et al.* 2007; Savelberg *et al.* 2007; Trans *et al.* 2009) . However WBV is a training method that has recently been developed and introduced as a rehabilitative protocol (Moezy *et al.* 2008). Although the high transmission of mechanical oscillations (30-50Hz) has been suggested at improving muscle strength and power, this in turn may lead to physiological changes at numerous levels including stimulus of skin response, muscle spindles, joint mechanoreceptors and neurotransmitter concentrations (Schuhfried *et al.* 2005). Moezy *et al.* (2008) presented evidence that improvement in postural control over 12 sessions of WBV training was significantly ($p \leq .05$) greater than conventional strength training over the same time period, this included centre of pressure (COP) distribution during dynamic and static conditions and also joint position sense. The study used ACL reconstruction patients as participants so has limited cross over effect to functional ankle instability groups and their contrasts in the two interventions between pre and post were carried out as t-tests, as opposed to a two-way ANOVA.

Mahieu *et al.* (2006) is one of the few researchers who have used a trained athletic population to assess the effect of vibration on balance and postural control. Thirty three competitive Belgium Skiers combined traditional strength training with WBV vibration training over a six week period. Although explosive power and plantar-flexor peak power where improved with WBV training, postural control did not change (Mahieu *et al.* 2006). Mahieu *et al.* (2006) speculates that WBV training only has a positive significant effect when the postural control of the subjects is disturbed or altered due to injury of neurological state. In the case of this research all subjects where young and healthy with no history of ankle trauma or instability and the frequency of the amplitude of training frequency (<26Hz) can be questioned with regards to optimal effect (Mester *et al.* 2006).

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Recent research conducted with older populations has supported the use of vibration training in improving balance and postural control (Bruyere *et al.* 2005; Bogaerts *et al.* 2007; Rees *et al.* 2009). Bogaerts *et al.* (2007) looked at the effect of a 1 year vibration training in conjunction with cardiovascular, strength and flexibility classes. Their results suggest WBV training may help reduce fall risk in the elderly due to the improved muscular strength and extensive stimulation of proprioceptive pathways (Bogaerts *et al.* 2007). However it should be noted that the research failed to find any statistical significant difference in any of the postural control variables they examined and therefore caution needs to be taken before assuming vibration training was the reason for reduced risk of fall.

Rees *et al.* (2009) looked to examine single legged balance in healthy older populations. Participants where arranged in vibration exercise, conventional exercise and control groups and asked to complete an 8 week training program. Single legged balance was significantly improved in the vibration training group compared to conventional exercise and control (Rees *et al.* 2009). Rees *et al.* (2009) suggest that the results provide efficacy for the use of vibration training in healthy well conditioned individuals as it is well tolerated, with no reports of adverse side effects. However, the research does point out that single legged static balance alone cannot be a significant predictor of injury and that their results suggest that those populations with initially poorer baseline balance score may gain significantly greater benefits from vibration training.

All studies using elderly populations do however acknowledge that age related changes in muscle physiology, proprioception and stability (Lord *et al.* 1994); making cross comparisons with younger more athletic populations difficult. Also the above studies assumed that vibration training alone is providing enough stimuli to improve postural control and balance, negating the evidence of unstable surface training and wobble board technology (Waddington *et al.* 1999; Waddington and Adams 2004; Emery *et al.* 2005).

To the author's knowledge only one study has looked to combine both vibration training and wobble board training, (Trans *et al.* 2009). WBV training has typically been applied on a stable WBV-platform, but recently a vibration platform built into a balance board has been introduced, thus increasing the demand of stabilization and postural control to the patient (Trans *et al.* 2009). The Vibrosphere ™ is a device that incorporates a wobble board design which vibrates under foot with different difficulty pads to increase or decrease displacement as well as the option to also alter vibration (Hz). Trans *et al.* (2009) research compared classical vibration training on a stable platform with vibration training on a wobble board within knee osteoarthritis patients. The researched indicated that although stable platform vibration improved isometric knee extension strength ($p<.001$), threshold detection of passive movement was significantly improved with individuals using the vibrosphere ™ ($p<.033$) compared to control [Figure 2.3] (Trans *et al.* 2009).

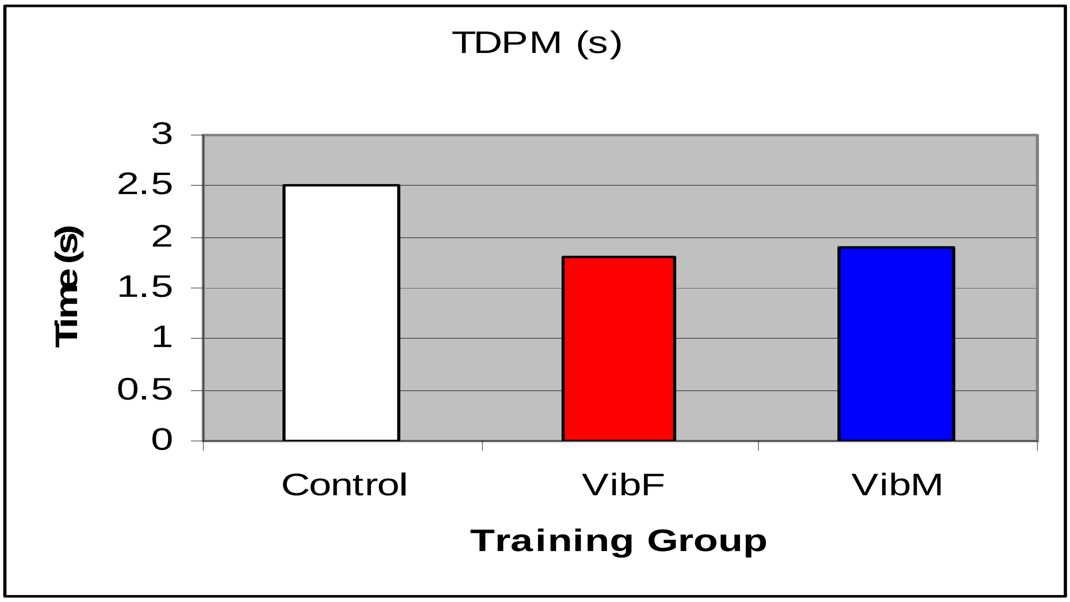

Figure 2.3 Threshold for detection of passive movements (TDPM). Follow-up average TDPM values (seconds) after 8 weeks in the VibF (Vibrosphere), VibM (Stable platform, and Con (Control) groups (Trans *et al.* 2009).

However, more data is needed to determine if WBV is an effective intervention in other areas of injury prevention or rehabilitation. The range of data collected across studies so far is insufficient to conclude whether WBV training effects balance, functional strength and muscle spindle sensitivity (Hopkins *et al.* 2008)

2.6 Purpose of present study

There is little scientific evidence with regard to the effects of WBVT on proprioception and postural stability in competitive athletes (Moezy *et al.* 2008). The findings of related studies suggest that effective rehabilitation programmes using Vibration therapy within older populations show positive effects on postural control and balance (Bruyere *et al.* 2005; Bogaerts *et al.* 2007; Rees *et al.* 2009; Trans *et al.* 2009). However there is limited research on the effect of vibration training on balance and postural control in athletic populations suffering ankle instability and associated deficits. It however seems clear that fall preventions and the ability to maintained a balance and postural control is key in both the elderly and FAI populations (Hertel 2000; Trans *et al.* 2009). It could therefore be argued improvements in elderly groups may also be seen in athletic p[populations.

The present study looks to examine the effect of vibration training on postural control, muscle function and functional strength parameter within a young ankle instable population. This information will not only help clinicians in their quest for new and innovative rehabilitation tools but will also help direct further research into classical stable platform vibration and contemporary wobble board vibration theories. It is hypothesised that vibration training inducing body perturbations in various ways (feed-forward versus feedback response) will improve postural control, muscle function and functional strength within functionally unstable ankle populations and this will be reflected in comparison with control groups.

Chapter 3 - The effects of 6 weeks whole body vibration training on balance and muscle fatigue in recreational dancers with functionally unstable ankles.

3.1 Abstract

Background: Functional ankle instability (FAI) is a common condition following ankle injury characterised by increased risk of further injury due to decreased balance and muscle function. Ankle sprains are a common acute form of injury suffered in dancing and loss of balance can affect not only risk of injury but also performance aesthetics. Whole body vibration training (WBVT) is a new rehabilitation method that has been linked with improving balance and muscle function in other populations. **Objective:** To determine the effect of six -week WBVT on static single leg balance, Star excursion balance test (SEBT) and peroneus longus muscle fatigue in dancers with unilateral FAI. **Methods:** Thirty-eight female recreational dancers with self reported unilateral FAI were randomly assigned in two groups; WBVT and Control. Absolute centre of mass (COM) distribution during single leg stance, SEBT normalised research distances and peroneus longus mean power frequency (f_{med}) where measured pre and post six-week intervention in both groups. **Results:** There was a significant improvement in COM distribution ($p<0.05$), and four of the eight planes of direction in the SEBT ($p<0.05$) compared to control groups during the course of the six week training intervention. There was no evidence of improvement in Peroneus longus (f_{med}) over time ($p = 0.915$) in either group. **Conclusions:** WBVT improved static balance and SEBT scores amongst dancers exhibiting ankle instability but did not affect peroneus longus muscle fatigue. There is a need for further research into the effects of WBVT compared to traditional rehabilitation methods.

3.2 Introduction

Recent research has found the ankle to be the second most commonly injured body site in sport, with ankle sprain being the most common type of ankle injury particularly prevalent among dance populations due to the nature of the activity (Fong *et al.* 2007b; O'Loughlin *et al.* 2008). Dance requires its participants to frequently jump and land on one leg, as well as performance of specific aesthetic movement patterns of the foot, all of which presents a higher risk for ankle sprains (Thacker *et al.* 1999). A functional instability in the ankle may persist after initial injury leading to an increased risk of recurrent ankle injury and subsequent time loss and distress to the athlete (Bernier and Perrin 1998; Hertel 2000; Rose *et al.* 2000; Konradsen *et al.* 2002; Ross *et al.* 2009a).

Functional ankle instability (FAI) is a condition characterised by repetitive episodes of "giving way" and/or incidence of recurrent ankle sprains (Tropp 2002). While the cause of FAI remains unclear, it has been suggested that both passive structures such as ligaments, articular surface of the ankle and neurological structures are damaged at the time of an ankle sprain contributing to recurrent instability (Palmieri-Smith *et al.* 2009). These neurological impairments include postural control (Konradsen 2002a; Sesma *et al.* 2008; Arnold *et al.* 2009; Ross *et al.* 2009b; Salavati *et al.* 2009; Sefton *et al.* 2009), dynamic balance (Olmsted *et al.* 2002; Hertel *et al.* 2006; Wikstrom *et al.* 2007; Brumitt 2008; Hardy *et al.* 2008; McKeon *et al.* 2008; Eechaute *et al.* 2009) and muscle fatigue (Tropp 1986; Konradsen *et al.* 1997; Adamo *et al.* 2002; Gribble and Hertel 2004; Gribble *et al.* 2004; Powers *et al.* 2004; South and George 2007;

Mitchell *et al.* 2008a; Palmieri-Smith *et al.* 2009). Therefore exercises that increase static/dynamic balance and fatigue resistance should be routinely performed following ankle injury to allow a safe return to sporting activity (Sekir *et al.* 2008a). This is particularly prevalent among female ballet dancers due to the time they spend *en pointe* (balancing on the tips of their toes in specially made shoes) and can have an impact on performance and career progression (O'Loughlin *et al.* 2008).

Whole body vibration training (WBVT) is a training method which has been recently introduced as a rehabilitative tool among clinicians (Torvinen *et al.* 2002a; Delecluse *et al.* 2003; Bogaerts *et al.* 2007; Kawanabe *et al.* 2007; Melnyk *et al.* 2008; Moezy *et al.* 2008; Rees *et al.* 2009; Trans *et al.* 2009). It has been hypothesised that the transmission of mechanical oscillations from the vibrating platform may lead to physiological changes in muscle spindles, joint mechanoreceptors, higher brain activity and strength and power properties (Moezy *et al.* 2008). WBVT has also been reported as improving balance scores within certain populations. Recent research conducted by Rees *et al.* (2009) identified that 8 weeks of WBVT significantly improved single leg static balance. Other clinical research has concurred that WBVT improves balance capabilities (Bruyere *et al.* 2005; Kawanabe *et al.* 2007). However it should be noted that these studies have all been conducted within elderly populations and thus comparison with younger active populations is difficult. Moezey *et al.*(2008) identified that WBVT training significantly improved balance and joint position sense in anterior cruciate ligament reconstruction patients allowing them to return to full activity as well as giving them an increased satisfaction with the rehabilitation process. Although there is support for the use of WBVT as a rehabilitation method, other studies have reported equivocal improvement in balance with vibration training within young healthy populations (Torvinen *et al.* 2002a; Torvinen *et al.* 2003). However it should be noted the researchers identified improvements in lower limb strength and power performance which were acknowledged as important components of lower limb function and injury prevention (Torvinen *et al.* 2002a). Other investigators have also identified the need for more then one dependent variable to be investigated when examining ankle injury, with a combination of static and dynamic measures as well as muscle function (Ross *et al.* 2009b).

Consequently, there is little scientific evidence with regard to the effects of WBVT as a rehabilitation tool for those suffering FAI symptoms. Accordingly the aim of this study is to investigate the effect of 6 weeks progressive WBVT on static and dynamic balance as well as muscle fatigue of the peroneus longus within dancers reporting FAI.

3.3 Methods

Participants

38 female dancers (Age 19 $\pm$ 1.1 years; Height 163.6 $\pm$ 7.3 cm; Weight 60.3 $\pm$ 6.3 kg) from a University dance department volunteered to take part in the study. The inclusion criteria for participation in this study were self reported unilateral chronic ankle instability, including a history of more than 1 lateral ankle sprain within the past 2 years and recurrent feeling of "giving way". Subjects completed a Cumberland Ankle Instability Tool questionnaire (CAIT) to determine their inclusion. The tool is a

questionnaire with 9 adjectival scale questions that generates a score between 0 and 30 and has high reliability and discriminative validity (Hiller *et al.* 2006). Scores of ≤ 23 indicate functional ankle instability. Exclusion criteria for all patients included an ankle injury during the previous 6 weeks, any balance or vestibular disorder, any history of lower limb breaks or fractures, previous ankle, knee or hip surgery and/or current head injury. All participants gave informed consent and the study was approved by the local ethics committee. According to the results of the CAIT (Table 3), 19 subjects where randomly assigned to the vibration training group and 19 where assigned to the control group (names where pulled from a hat by the researcher). Thirty-two reported functional instability in their right ankle and 6 in the left.

Table 3 Subject Characteristic (mean ± SD) and right (R) and (L) affected limb.

Group	N	Age (yr)	Mass (kg)	Height (cm)	Affected limb	CAIT Score
Vibration	19	19 ± 0.8	60.3 ± 5.7	164.5 **+** 8.7	R 19 L0	18.4± 1.3
Control	19	19 ± 1.3	60.2 ± 6.9	162.6 ± 5.5	R 13 L6	18 ± 1.5

Testing Procedures

Single leg balance test

Participants where asked to remain as motionless as possible whilst standing on their test leg, on the RSscan ® pressure mat (RScan, Ipswich) As the inability to maintain quite stance during single leg standing has consistently been associated with ankle instability (Arnold *et al.* 2009; Ross *et al.* 2009b). Participants performed all tests with their eyes open, hands on hips, and their non-weight bearing leg flexed at the knee (Figure 3). All participants performed the test bare foot to eliminate the effect of shoe type (McKay *et al.* 2001). Participants performed one 10 sec practice trial, followed by two 30 sec testing trials. Participants rested 20 sec between trials as suggested in previous research (Ross *et al.* 2009b). Trials were repeated if participants lost balance, hopped or touched down on the non-weight bearing leg. The centre of pressure (COP) area was recorded which represented the maximum anterior, posterior, medial, and lateral sway during the given time (Ross *et al.* 2009b). The average of both trials was recorded. Increased values in the mean radius of the COP suggest decreased postural control, whereas a decreased value suggests increased postural stability (Le Clair and Riach 1996).

Figure 3 Single leg static balance on RSscan ® pressure mat

Star excursion balance test (SEBT)

The Star Excursion Balance Test (SEBT) has been shown to have a strong intra-test and inter-tester reliability (Kinzey and Armstrong 1998; Hertel *et al.* 2000). The participants performed the SEBT while standing barefoot on their unstable ankle in a grid laid on the floor with 8 lines extending at 45 degree increments from the centre of the grid (Figure 3.1). As in previous studies, the length and width of the foot was measured and meticulously placed so that the geometric centre of the foot was aligned to the centre of the eight line star (Hertel *et al.* 2006). Participants maintained a single leg stance while reaching with their non-weight bearing leg as far as possible along a chosen line, with the aim of touching the furthest point with the most distal part of the foot. A mark was made by the investigator at the point of touchdown of the reaching leg. Reach distances where measured from the centre of the grid and divided by leg length and multiplied by 100 to calculate reach distance as a percentage of leg length (%MAXD) normalising data (Gribble and Hertel 2003). Leg length was measured with the participant lying supine, as the distance from the anterior superior iliac spine to the centre of the ipsilateral medial malleolus using a anthropometric tape measure (Gribble and Hertel 2003). If at any point the participant used their reaching leg for substantial support, removed their foot from the centre of the grid or lost balance during the trial, the trial was discarded and repeated. The order of reaching directions was randomized by the investigator and repeated in this order for the post treatment trials. The average of three trials was taken.

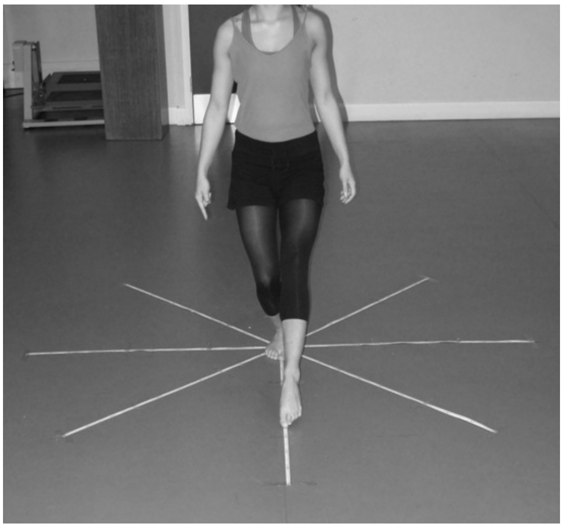

Figure 3.1 SEBT anterior view, illustrating anterior reach direction.

Mean power frequency (f_{med}) of the peroneus longus

It has been shown that muscle fatigue can significantly impair postural control (Corbeil *et al.* 2003; Gribble and Hertel 2004; Gribble *et al.* 2004) Thus; it is likely that improvements in muscle strength and endurance through training would improve stability. Generally, fatigue is considered as a failure to maintain a required or expected force output. It is well accepted that the inability to maintain this force is associated with changes in muscle electrical activity (Vøllestad 1997). Because of this, electromyography (EMG) is commonly used to assess fatigue (Powers *et al.* 2004). As a muscle fatigues, changes in EMG frequency characteristics (e.g., median power frequency) can be used to quantify the rate at which fatigue occurs (Dimitrova and Dimitrov 2003). Whereas EMG amplitude increases during fatigue, the mean power frequency actually decreases, reflecting decreases in muscle-fibre conduction velocity (Dimitrova and Dimitrov 2003).

Before testing, each participant's shin area was shaved (if necessary), debrided, and cleaned with isopropyl alcohol for placement of the EMG electrodes using 1 cm diameter circular Ag/AgCl electrodes. The electrodes were placed distal to the caput fibulae, one-quarter of the distance between the caput fibulae and the lateral malleolus along the line connecting these anatomical landmarks. Electrodes were placed longitudinally along this line with a 2 cm inter-electrode distance and a reference electrode was placed on the head of the fibula (Gruneberg *et al.* 2003). Proper positioning of the electrodes over the corresponding muscle belly was verified by inspection during maximal voluntary contractions in an upright standing position (Figure 3.2). Surface EMG measurements were collected using a commercial data acquisition system (Powerlab, AD instruments, UK). Signals were amplified and fed into a personal computer after analogue-to-digital conversion. The EMG signals were band-pass filtered at 10 and 500 Hz and sampled at 2000 Hz using data acquisition Software (Chart v 5.1; AD Instruments, UK).

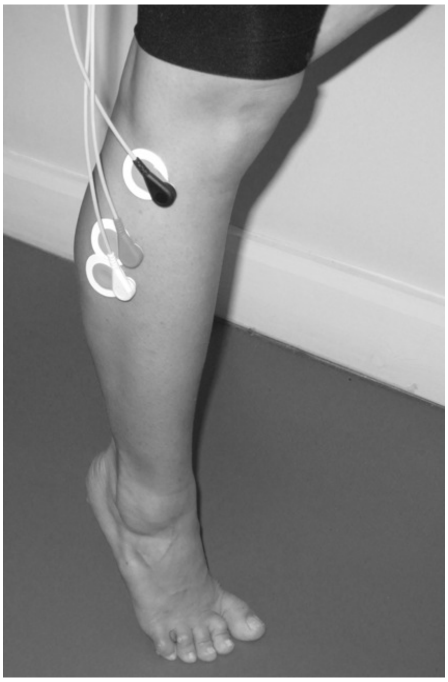

Figure 3.2 EMG recording of peroneus longus during demi-pointe

Although ankle muscular activity has been widely studied in individuals with FAI (Vaes *et al.* 2002; Forestier and Toschi 2005; Shima *et al.* 2005; Delahunt 2007; Palmieri-Smith *et al.* 2009), those studies have been performed in extremely controlled conditions and few focused on actual conditions, present in dance, as proposed in this study (Suda *et al.* 2009). *Demi-pointe* is a ballet position in which the subject stands on the toes, that is, with the weight of the body resting on the metatarsals (Hiller *et al.* 2004). Subjects were allowed to use a barre to stabilise themselves during the *demi-pointe* stance for 30 seconds as it was deemed too difficult by participant to maintain balance for 30 seconds unsupported, as reported in previous research (Hiller *et al.* 2004), and as the aim of the testing was to examine the mean power frequency of the peroneus longus during the task and not the balance of the participant. The same examiner was used during all testing to access correct height for *demi-pointe* and support for the *demi-pointe* was restricted to a single finger on ballet barre. For the current investigation, the mean power frequency of the first 5-second interval, which we considered the non-fatigued, or baseline was normalised. Mean power frequency was calculated using a custom developed excel spreadsheet. Thus, the data for the final 25-30 sec interval was calculated relative to the first 5-second interval as a percentage drop in mean power frequency and used for statistical analysis (Powers *et al.* 2004).

Intervention:

Whole Body Vibration Training

All participants in the treatment group followed a structured 6 week progressive vibration programme consisting of single leg exercises increasing in duration and vibration frequency as the training progressed. Training exercises where based on (Cochrane and Stannard 2005a) due to their similar population and the Hertz and Time progression was used to provide progressive overload as with previous research (Van Nes *et al.* 2006). Rittwegar (2010) identifies time under tension or in the case of vibration training, time under exposure as key to progressive overload, and hence why exposures goes up 120 seconds every two weeks. At the beginning of 6 weeks, participants were randomly assigned in two groups (WBVT and Control groups). The WBVT group did exercises on vibration platform (Bosco, Greece) while bare foot. Table 3.1 shows the details of the WBVT program. The participants in the Control group refrained from any ankle specific strength/balance training during the 6-week period and continued their normal training regime.

Table 3.1 6 week Whole body vibration Training Plan

	Day 1	**Day 2**
Week 1	Single leg heal raises 50 sec x 3 each leg @ 30Hz	Single leg heal raises 50 sec x 3 each leg @ 30Hz
	Single leg squats 50 sec x 3 each leg @ 30Hz	Single leg squats 50 sec x 3 each leg @ 30Hz
WBV Duration (min)	10min	10 min
Week 2	Single leg heal raises 50 sec x 3 each leg @ 30Hz	Single leg heal raises 50 sec x 3 each leg @ 30Hz
	Single leg squats 50 sec x 3 each leg @ 30Hz	Single leg squats 50 sec x 3 each leg @ 30Hz
WBV Duration (min)	10min	10 min
Week 3	Single leg heal raises 60 sec x 3 each leg @ 35Hz	Single leg heal raises 60 sec x 3 each leg @ 35Hz
	Single leg squats 60 sec x 3 each leg @ 35Hz	Single leg squats 60 sec x 3 each leg @ 35Hz
WBV Duration (min)	12 min	12min
Week 4	Single leg heal raises 60 sec x 3 each leg @ 35Hz	Single leg heal raises 60sec x 3 each leg @ 35Hz
	Single leg squats 60 sec x 3 each leg @ 35Hz	Single leg squats 60 sec x 3 each leg @ 35Hz
WBV Duration (min)	12min	12 min

Week 5	Single leg heal raises 70 sec x 3 each leg @ 40Hz	Single leg heal raises 70 sec x 3 each leg @ 40Hz
	Single leg squats 70 sec x 3 each leg @ 40Hz	Single leg squats 70 sec x 3 each leg @ 40Hz
WBV Duration (min)	14min	14 min
Week 6	Single leg heal raises 70 sec x 3 each leg @ 40Hz	Single leg heal raises 70 sec x 3 each leg @ 40Hz
	Single leg squats 70 sec x 3 each leg @ 40Hz	Single leg squats 70 sec x 3 each leg @ 40Hz
WBV Duration (min)	14 min	14 min

Statistical Analysis

The dependent variables were the normalised reach distance expressed as a percentage of subject's leg length, mean power frequency (f_{med}) and centre of mass distribution (COM). All data were analysed using a 2-way ANOVA with repeated measures, with one between-subjects factor (Treatment group; WBVT vs Control) and one within-subjects factor (Time; Pre- vs Post-training). Data was analysed using SPSS for windows, Version 16.0 (SPSS Inc, IL). An alpha level of $p<0.05$ was determined to be significant for all statistical comparisons.

3.4 Results

Star excursion balance test results

There were significant improvements in Anterior ($p = 0.036$), Anterior Medial ($P= 0.038$), Medial ($p = 0.047$) and Anterior Lateral ($P = 0.015$) amongst the WBVT group in comparison to the control group (Table 3.2) as identified by a significant group-by-time interaction. There were no significant difference/interactions between groups in the planes of Posterior Medial (p = 0.23), Posterior (P = 0.58), Posterior Lateral (p = 0.23) and Lateral (p = 0.19).).

Table 3.2 Means and Standard deviations of normalized reach distances (reach distance is cm/leg length in cm). All testing was conducted on a previously identified unstable ankle**.**

	Vibration (n19)		**Control (n19)**		
	Pre Intervention (%MAXD)	Post Intervention (%MAXD)	Pre Intervention (%MAXD)	Post Intervention (%MAXD)	Group Min Effect (P value)
ANT *	75.5 ± 7.1	80.2 ± 7.2	74.7 ± 6	74.9 ± 6.1	0.036*
AM *	81 ± 5.5	85 ± 9.2	79. 1 ± 6	78.1 ± 7.7	0.038*
MD *	84.8 ± 8	92 ± 12.5	82.4 ± 6.6	83.7 ± 7.8	0.047*
PM	88. 9 ± 9.3	97 ± 13.5	84.9 ± 9	87.5 ± 10.3	0.23
PO	87.6 ± 10	93.9 ± 14.2	86.3 ± 11.3	89.9 ± 12.2	0.58
PL	85.4 ± 10.8	93.8 ± 11.6	82.6 ± 14.4	86.2 ± 13.4	0.23
LAT	78.9 ± 11.6	91.1 ± 12.3	74.4 ± 15.6	80.4 ± 15.7	0.19
AL *	68.5 ± 9.4	79.4 ± 8.5	70.5 ± 8.9	74. 7 ± 9.7	0.015*

Abbreviations: **AL**, anterolateral; **AM**, anteromedial; **ANT**, anterior; **LAT**; lateral; **MD**, medial; **PL**, posterolateral; **PM**, posteromedial; **PO**, posterior. (* Indicates significance p<.05).

Mean power frequency (*f_{med}*) and centre of pressure distribution results

There was no significant difference in percentage decrease in MPF between groups over the 30 sec period that the participants were on *demi-pointe* (p = 0.915). Though a significant difference between COP between the WBVT and control group (p = 0.04) was noted (Table 3.3).

Table 3.3 Means and Standard Deviation of percentage decrease in MPF (MPF Dif %) calculated from 0-5 sec MPF and 25-30 sec MPF during the course of 30 sec on *demi-pointe.* The values are shown as percentages of Hertz difference in values during 0-5 sec and 25-30 sec in MPF over the course of the 30 sec and Centre of pressure distribution (COP) shown as cm2. (* Indicates significance P<.05).

Vibration (n19)		**Control (n19)**		
Pre	**Post**	**Pre**	**Post**	**Significance***
MPF Dif %	**MPF Dif %**	**MPF Dif %**	**MPF Dif %**	**Group Main Effect (P value)**
6.2 ± 3.6	6.6 ± 3.6	7.1 ± 3.9	7.3 ± 2.3	0.915
COP distribution (cm_2)	**COP distribution (cm_2)**	**COP distribution (cm_2)**	**COP distribution (cm_2)**	**Group Main Effect (P value)**
1.05 ± 0.57	0.33 ± 0.42	1.01 ± 0.44	0.82 ± 0.46	0.04*

3.5 Discussion

As far as we are aware, this is the first randomised control trial investigating the effect of WBVT on balance and muscle function in dancers suffering FAI. For this investigation we hypothesised that peroneus longus fatigue would be reduced and static and SEBT excursion balance would improve after six weeks of progressive WBVT in comparison to those in the control group. The results of this study suggest that while static and dynamic balance significantly improved over certain planes of motion in those undertaking WBVT, muscle fatigue did not significantly differ between groups.

WBVT has been used by a limited number of researchers as a method of rehabilitation (Torvinen *et al.* 2002a; Delecluse *et al.* 2003; Bogaerts *et al.* 2007; Kawanabe *et al.* 2007; Melnyk *et al.* 2008; Moezy *et al.* 2008; Rees *et al.* 2009; Trans *et al.* 2009). However little has been done amongst young active participants suffering FAI. As with previous research (Rees *et al.* 2009) single leg static balance improved with the implementation of WBVT, however this improvement was demonstrated over a six week period training, twice a week were as previous research had gone for a longer >8 week period with >3 sessions a week. This supports Arnold *et al.,* (2009) suggestion that more research is needed in both sedentary and athletic populations to identify optimum rehabilitation duration for improving and monitoring static balance.

Interestingly, the initial centre of mass distribution score were less then those identified in previous research within FAI populations (Arnold *et al.* 2009). Explanations for this could be the relatively high CAIT scores reported by participants indicating that the severity of instability was less than those in previous research (Sesma *et al.* 2008) or a more likely reason could be in line with Aydin *et al.*(2002) which identified female gymnasts as having a greater joint position sense and kinaesthetic awareness due to the activity they compete in being largely focused on balance and correct form. Dance also has similar components to competitive gymnastics and may warrant, as a population, further investigation to identify differences in general university populations used in previous FAI research.

Dance requires both static and dynamic balance as key components to successful performance (O'Loughlin *et al.* 2008) therefore the improved SEBT score of those in the WBVT group compared to the control group may be of greater significance to clinicians looking at successful rehabilitation methods than static balance tests alone. Although it should be noted that there was only an improvement over four planes of motion (Anterior, Anterior Medial, Medial and Anterior Lateral) and there is debate on the significance of these planes of motion in identifying stability improvements in those suffering balance deficits (Plisky *et al.* 2006; Fitzgerald *et al.* 2010).

The Star Excursion Balance test consists of complex closed kinetic chain motions of the stance leg. The subject has to flex their hip, knee, and dorsiflex the foot while balancing on their injured ankle. Concentric and eccentric muscle contractions, proprioception, as well as postural control are simultaneously involved (Chaiwanichsiri *et al.* 2005). With this in mind, STAR excursion training itself may have caused an improvement in scores as reported previously by Chaiwanichsiri (2005). However this is unlikely in this study considering the relatively low number of repetitions but may explain some of the improvements seen among the control groups and warrant further investigation of the test as a training intervention alone. As we did not assess ankle dorsiflexion flexibility it is impossible to say whether an increase in flexibility due to WBVT improved SEBT scores. However vibration training has been reported as improving flexibility (Cochrane and Stannard 2005b) and may require future investigation.

No difference was observed in Peroneus longus (f_{med}) in either the WBVT group or the control group. South and George (2007) report that fatigue of the peroneus muscles did not affect ankle join position sense, suggesting that either proprioception is fatigue resistant in the peroneus muscles or other structures in the ankle (e.g. ligaments, capsule) may play a significant proprioceptive role. Powers *et al.* (2004) also found that 6 weeks strength and proprioception training had no effect on peroneus fatigue in those suffering FAI. The present research agrees with Powers *et al.* (2004) that one reason for this may be the training stimulus of 6 weeks WBVT may not have been sufficient enough to instigate appropriate changes in peroneus longus activity, or the task itself on *demi-pointe* was not tasking enough to establish appropriate levels of fatigue. However, it is felt that further research is required to identify appropriate dance specific fatiguing exercises. As noted by previous research, dance movements such as *demi-pointe* are perceived by the investigators as being too difficult to maintain for significant periods without failure which is not necessarily due to fatigue (Hiller *et al.* 2004).

It was also difficult in this study to objectively format the rehabilitation protocol due to the lack of evidence based research for young FAI populations and WBVT. Therefore we chose to adapt previous models of balance training and vibration (Runge *et al.* 2000; Bruyere *et al.* 2005). However these were often based around fall prevention populations and often limited to sit and stand performance (Runge *et al.* 2000), something that has little relevance to athletic performance. Therefore one of the greatest difficulties that were encountered in developing the training protocol was the lack of objective evidence to supports the use of WBVT in FAI populations.

When interpreting the results of the current study one has to remember that the WBVT group participants also did dynamic exercise movements during vibration exposure (single leg squats and heel raises), and thus, one could suspect that the improvements may be attributed to these exercises (Torvinen *et al.* 2002a). However, it remains unlikely that these exercises alone were behind the improvement in static and dynamic balance without some contribution from the vibration component. Further research is required to assess the effectiveness of WBVT against traditional methods of rehabilitation amongst functionally unstable populations.

3.6 Conclusions

It appears that WBVT improves single leg balance and SEBT performance in dancers with unilateral FAI. The positive effect of WBVT, its short time of training and adherence rate in the present study supports the need for future research on this type of training as new method of ankle injury prevention in dance populations. Further research is needed to compare WBVT to classical methods of rehabilitation.

Chapter 4- An investigation into the effect of 6 weeks combined vibration and wobble board training on balance and dynamic stability in footballers with functional ankle instability.

4.1 Abstract

Background: Functional ankle instability (FAI) is a common condition following ankle injury characterised by increased risk of further injury due to decreased balance and muscle function. Ankle sprains are a common acute form of injury suffered in football. Vibration training is a new rehabilitation method that has been linked with improving balance and muscle function and new rehabilitation equipment is using this potential for quicker recovery. **Objective:** To compare the effectiveness of combined vibration and balance training with balance training alone over a six-week period on absolute centre of mass (COM) distribution, modified star excursion balance test (SEBT) and single leg triple hop for distance (SLTHD) in footballers with unilateral FAI. **Methods:** Thirty-Three male semi-professional footballers with self reported unilateral FAI were randomly assigned in 3 groups; vibration and wobble board, wobble board and Control. Absolute centre of mass (COM) distribution during single leg stance, modified SEBT research distances and SLTHD where measured pre and post six-week intervention in all groups. **Results:** Amongst the combined vibration and wobble board group there was a significant improvement in COM distribution ($p<0.05$), and two of the three planes of direction in the modified SEBT ($p<0.05$) as well as SLTHD ($p<0.05$) compared to wobble board alone training group during the course of the six week training intervention. **Conclusions:** Combined vibration and wobble board training improved static balance, modified SEBT scores and SLTHD

amongst footballers suffering FAI. There is a need further research into the exact physiological reasoning behind the seen results and the effect such improvements have on actual injury risk over time. Also how this data relates to actual injury occurrence in footballers.

4.2 Introduction

Ankle inversion sprain is a common injury in both sportsmen and physically active individuals. The recurrence rate for this type of injury among these populations has been reported to be as high as 80% (Yeung *et al.* 1994). Football is a complex contact sport, associated with high levels of injury risk (Cloke *et al.* 2009). Of these, ankle injuries are commonly reported accounting for between 11-18% of all injuries the majority of which are sprains (Hawkins and Fuller 1999; Woods *et al.* 2003).

The most common complication following ankle sprain is functional instability (Suda *et al.* 2009), which is a condition characterised by repetitive episodes of "giving way" and/or incidence of recurrent ankle sprain (Tropp 2002), with the sufferer complaining of instability without any evidence of mechanical disruption to the ligaments and joint structure of the ankle. Functional ankle instability (FAI) can be considered a multi-factorial condition involving neurological, muscular and sensorimeter factors all contributing to a deficit in balance and dynamic muscle strength (Konradsen and Magnusson 2000). These impairments have been shown to include postural control (Konradsen 2002a; Arnold *et al.* 2009; Ross *et al.* 2009b), dynamic balance (Olmsted *et al.* 2002; Hertel *et al.* 2006) and muscle function (Tropp 1986; Konradsen *et al.* 1997; Eechaute *et al.* 2009). Arnason *et al.* (2004) identified that previously sprained ankles in footballers had as much as a five fold increase in injury risk in comparison to their uninjured counterparts, indicating not only significant instability following ankle sprain but also the necessity for a more successful rehabilitation program.

Classical preventative rehabilitation using wobble board techniques have been popular amongst clinicians for a number of years (Holmes and Delahunt 2009), particularly amongst football populations (Ergen and Ulkar 2008). Although research suggests an improvement in symptoms of ankle instability with the intervention of wobble board training (Emery *et al.* 2005; Lee and Lin 2008; Fitzgerald *et al.* 2010), others contradict this claim indicating no significant improvement in balance or muscle function (Bernier and Perrin 1998; Kaminski *et al.* 2003; Powers *et al.* 2004; Verhagen *et al.* 2005). Due to such contrasting evidence on the effectiveness of a single training method (wobble board). Amongst, various populations of dancers, footballers and collage students. Coaches and athletes have begun to implement more then one rehabilitation method in an attempt to decrease rehabilitation time and produce a positive cumulative effect, such as combined wobble board and theraband work (Hutchinson and Swan 2002; Verhagen *et al.* 2005).

Whole body vibration training (WBVT) is a training method which has been recently introduced as a rehabilitative tool among clinicians (Melnyk *et al.* 2008; Moezy *et al.* 2008; Rees *et al.* 2009; Trans *et al.* 2009). It has been hypothesised that the transmission of mechanical oscillations from the vibrating platform may lead to physiological changes in muscle spindles, joint mechanoreceptors, higher brain activity and hence strength and power properties (Moezy *et al.* 2008). WBVT has typically taken place on a stable platform, however recently a vibration system has been incorporated into a wobble board (Vibrosphere ^{TM}) which claims to incorporate the benefits of traditional vibration therapy with the added aspect of increased postural demand. This method of training has been shown to be successful in improving certain balance parameters in elderly populations (Trans *et al.* 2009), however there was no direct comparison with wobble board exercise alone, therefore the true contribution of the vibration component is difficult to identify.

The purpose of the present research therefore, is to examine the effect of six weeks combined vibration and wobble board training (Vibrosphere ^{TM}) against wobble board training alone on improving static/dynamic balance and functional strength over the course of a six week training cycle in amateur footballers suffering subjective functional ankle instability.

4.3 Methods

Participants

Thirty three male amateur football players volunteered to take part in the study (Table 4). The inclusion criteria for participation in this study were self reported unilateral chronic ankle instability, including a history of more than 1 lateral ankle sprain within the past 2 years and recurrent feeling of "giving way". Participants completed a Cumberland Ankle Instability Tool questionnaire (CAIT) to determine their inclusion. The tool is a questionnaire with 9 adjectival scale questions that generates a score between 0 and 30 and has high reliability and discriminative validity (Hiller *et al.*

2006). Scores of ≤ 23 indicate functional ankle instability. Exclusion criteria for all participants included an ankle injury during the previous 6 weeks, any balance or vestibular disorder, any history of lower limb breaks or fractures, previous ankle, knee or hip surgery and/or current head injury. Participants also presented negative results in the anterior drawer test which assesses the integrity of the anterior talofibular ligament and of talar tilt test that assess the calcaneofibular ligament integrity (Baumhauer *et al.* 1995; Hertel *et al.* 1999; Safran *et al.* 1999a).

All participants gave written informed consent and the study was approved by the local ethics committee. According to the results of the CAIT (Table 1), 11 participants where randomly assigned to the Vibration and wobble board training group (Vibrosphere ™), 11 were assigned to wobble board training alone and 11 were assigned to a control group. Twenty reported functional instability in their right ankle and 13 in the left.

Table 4 Participant Characteristic (mean ± SD) and right (R) and (L) affected limb.

Group	**N**	**Age (yr)**	**Mass (kg)**	**Height (cm)**	**Affected limb**	**CAIT Score**
Vibration and Wobble board	11	22. ± 3.	78.3 ± 7.7	174.5 ± 7.8	R=6 L=5	18.1 ± 0.9
Wobble board	11	22 ± 2	73.9 ± 4.7	171.2 ± 5.4	R=7 L=4	17.4 ±1.4
Control	11	23 ± 2	77.5 ± 7	176.5 ± 9	R=7 L=4	17.9 ± 1.3

Testing Protocol

Single leg balance test

Participants where asked to remain as motionless as possible whilst standing on their test leg, on the RSscan ® pressure mat (RScan, Ipswich, U.K) as the inability to maintain quiet stance during single leg standing has consistently been associated with ankle instability (Arnold *et al.* 2009; Ross *et al.* 2009b). Participants performed all tests with their eyes open, hands on hips, and their non-weight bearing leg flexed at the knee (Figure 4). All participants performed the test bare foot to eliminate the effect of shoe type (McKay *et al.* 2001). Participants performed one 10 sec practice trial, followed by two 30 sec testing trials. Participants rested 20 sec between trials as suggested in previous research (Ross *et al.* 2009b). Trials where repeated if participants lost balance, hopped or touched down on the non-weight bearing leg. The centre of pressure (COP) area was recorded which represented the maximum anterior, posterior, medial, and lateral sway during the given time (Ross *et al.* 2009b). The average of both trials was recorded. Increased values in the mean radius of the COP suggest decreased postural control, whereas a decreased value suggests increased postural stability (Le Clair and Riach 1996).

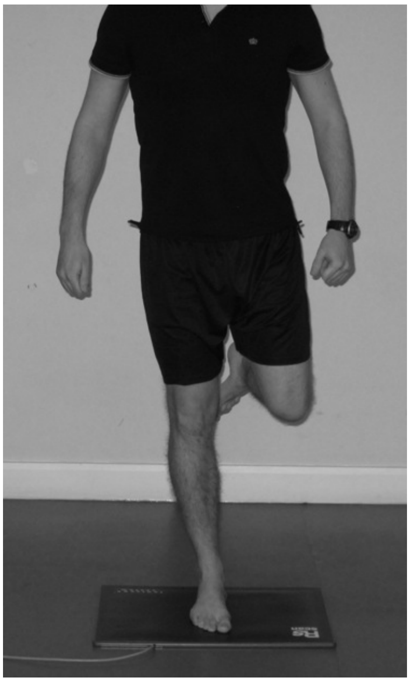

Figure 4 Mean COP excursion testing

Modified Star Excursion Balance Test (SEBT)

The Star Excursion Balance Test (SEBT) has been shown to have a strong intra-test and inter-tester reliability (Kinzey and Armstrong 1998; Hertel *et al.* 2000). The participants performed the SEBT while standing barefoot on their unstable ankle in a grid laid on the floor with 8 lines extending at 45 degree increments from the centre of the grid (Figure 4.1). As in previous studies (Gribble and Hertel 2003; Hertel *et al.* 2006), the length and width of the foot was measured and meticulously placed so that the geometric centre of the foot was aligned to the centre of the eight line star (Hertel *et al.* 2006). Participants maintained a single leg stance while reaching with their non-weight bearing leg as far as possible along a chosen line, with the aim of touching the furthest point with the most distal part of the foot. A mark was made by the investigator at the point of touchdown of the reaching leg. Reach distances where measured from the centre of the grid and divided by leg length and multiplied by 100 to calculate reach distance as a percentage of leg length (%MAXD) in order to normalise data (Gribble and Hertel 2003). Leg length was measured, with the participant lying supine, as the distance from the anterior superior iliac spine to the centre of the ipsilateral medial malleolus using a anthropometric tape measure (Gribble and Hertel 2003). If at any point the participant used their reaching leg for substantial support, removed their foot from the centre of the grid or lost balance during the trial, the trial was discarded and repeated.

Performance of all eight reach directions however was seen as unnecessary when evaluating for functional deficits related to FAI because of considerable redundancy among the reach directions reported (Hertel *et al.* 2006). Therefore the participants performed the anterior (Ant), posterior medial (PM), and posterior lateral (PL) SEBT directions that have been shown to be the most effective in assessing dynamic balance in participants with CAI (Hertel *et al.* 2006; Plisky *et al.* 2006). Each subject performed 3 practice trials in each of the three directions on identified leg followed by 5 min of rest before recording began. Participants then performed three trials in each direction on each limb. Ten seconds of rest were provided between individual reach trials (Martínez-Ramírez *et al.* 2010).

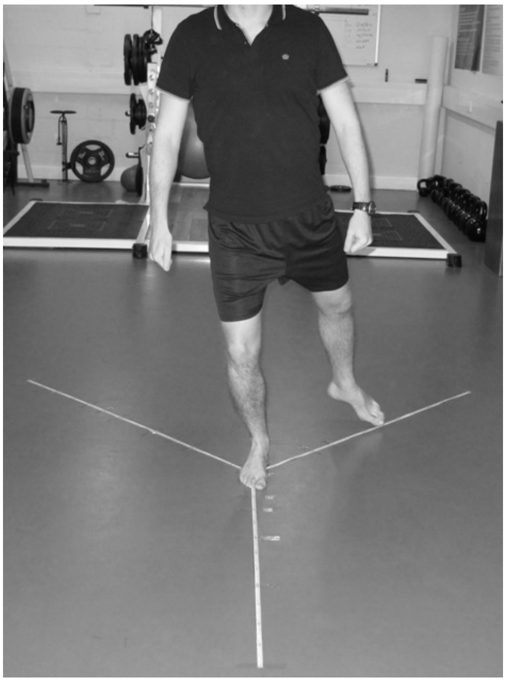

Figure 4.1 Modified SEBT

Single leg triple hop for distance (SLTHD)

Contemporary research is increasingly focusing on the application of landing test protocols (Wikstrom *et al.* 2004; Ross *et al.* 2005; Ross *et al.* 2009a). However these laboratory studies require sophisticated equipment and require time consuming analysis for each participant (Eechaute *et al.* 2009). Triple hop for distance is a valid clinical tool for assessing strength and power characteristics in healthy athletes, while tasking balance components (Hamilton *et al.* 2008). More recently it has also been reported as a valid and reliable assessment for athletes suffering FAI and as a monitoring tool of ankle function for clinicians (Sekir *et al.* 2008b).

A standard cloth tape measure was fixed to the ground, perpendicular to a starting line. Participants stood on the designated testing leg, with the great toe on the starting line. They performed 3 consecutive maximal hops forward on the affected limb. Arm swing was allowed. The investigator measured the distance hopped from the starting line to the point where the heel struck the ground upon completing the third hop (Bolgla and Keskula 1997).

All participants were allowed 1 to 3 practice trials (self-selected). A test trial was repeated if the participant was unable to complete a triple hop without losing balance and contacting the ground with the opposite leg. The maximum distance achieved during the 3 trials was recorded in centimetres and used for analysis. Participants wore self-selected athletic footwear during the test (Hamilton *et al.* 2008). The test-retest reliability of this standardized protocol has been demonstrated in previous research (Bolgla and Keskula 1997). All testing was completed at the end of static balance and modified SEBT to reduce the effects of fatigue on postural control (Harkins *et al.* 2005; Erkmen *et al.* 2009).

Combined vibration and wobble board training (Vibrosphere ™)

The training methodology was based on the Ergen and Ulkar (2008) recommendation for rehabilitation training in football players suffering functional deficits following ankle injury. Both training groups exercised twice a week for six weeks. All participants trained using their affected ankle only. Each training session was supervised by one of the members of the research team. Table 4.2 indicates the training undertaken over the six week duration. To ensure comparability between Vibrosphere ™ and wobble board training groups, the Vibrosphere ™ was used by both training groups. The researchers took this view to maintain validity when comparing both groups, so any differences could not be associated with using a different wobble board or training protocol. The function pads, which are designed to reduce stability and increase difficulty while on the Vibrosphere ™ where also used for both groups (figure 4.2). Training exercises where based on (Cochrane and Stannard 2005a) due to their similar population and the hertz and time progression was used to provide progressive overload as with previous research advocating these frequencies (Van Nes *et al.* 2006; Paradisis and Zacharogiannis 2007; Rehn *et al.* 2007). Rittwegar (2010) identifies time under tension or in the case of vibration training, time under exposure as key to progressive overload as well are frequency. However with a new piece of equipment the variables manipulated to create overload where task difficulty as recommended by Ergen and Ulkar, (2008) and decreasing stability using the function pads provided by Vibrosphere (under advice from the manufacturers).

Figure 4.2 Vibrosphere ™ training (www.promedvi.com)

Table 4.1 6 weekly training programme for Vibrosphere ™ and wobble group. Wobble board group completed exercises in absence of vibration.

Week 1				
Exercise	**Difficulty**	**Function Pad**	**Time**	**Hertz**
Standing on one leg	Static hands on hips	Dark blue-soft 2-Intermediate	2 x 45 each leg	30
Heel raises on one leg	Isometric with support	Dark blue-soft 2-Intermediate	2 x 45 each leg	30
Single leg step ups	Hands on hips	Dark blue-soft 2-Intermediate	2 x 45 each leg	30
Single leg straight leg dead lifts	Hands on hips	Dark blue-soft 2-Intermediate	2 x 45 each leg	30
Week 2				
Exercise	**Difficulty**	**Function Pad**	**Time**	**Hertz**
Standing on one leg	Static hands on hips	Dark blue-soft 2-Intermediate	2 x 45 each leg	30
Heel raises on one leg	Isometric with support	Dark blue-soft 2-Intermediate	2 x 45 each leg	30
Single leg step ups	Hands on hips	Dark blue-soft 2-Intermediate	2 x 45 each leg	30
Single leg straight leg dead lifts	Hands on hips	Dark blue-soft 2-Intermediate	2 x 45 each leg	30

Week 3				
Exercise	**Difficulty**	**Function Pad**	**Time**	**Hertz**
Standing on one leg	3kg medicine ball above head	Red -soft 3-difficult	2 x 45 each leg	35
Heel raises on one leg	Isometric with support	Red -soft 3-difficult	2 x 45 each leg	35
Single leg step ups	3kg medicine ball above head	Red -soft 3-difficult	2 x 45 each leg	35
Single leg straight leg dead lifts	3kg medicine ball in hands	Red -soft 3-difficult	2 x 45 each leg	35
Week 4				
Exercise	**Difficulty**	**Function Pad**	**Time**	**Hertz**
Standing on one leg	3kg medicine ball above head	Red -soft 3-difficult	2 x 45 each leg	35
Heel raises on one leg	Isometric with support	Red -soft 3-difficult	2 x 45 each leg	35
Single leg step ups	3kg medicine ball above head	Red -soft 3-difficult	2 x 45 each leg	35
Single leg straight leg dead lifts	3kg medicine ball in hands	Red -soft 3-difficult	2 x 45 each leg	35

Week 5				
Exercise	**Difficulty**	**Function Pad**	**Time**	**Hertz**
Standing on one leg	Volley ball back to partner	Blue-challenging fitness pad	2 x 45 each leg	40
Heel raises on one leg	Isometric with support	Blue-challenging fitness pad	2 x 45 each leg	40
Single leg step ups	3kg medicine ball above head	Blue-challenging fitness pad	2 x 45 each leg	40
Single leg straight leg dead lifts	3kg medicine ball in hands	Blue-challenging fitness pad	2 x 45 each leg	40
Week 6				
Exercise	**Difficulty**	**Function Pad**	**Time**	**Hertz**
Standing on one leg	Volley ball back to partner	Blue-challenging fitness pad	2 x 45 each leg	40
Heel raises on one leg	Isometric with support	Blue-challenging fitness pad	2 x 45 each leg	40
Single leg step ups	3kg medicine ball above head	Blue-challenging fitness pad	2 x 45 each leg	40
Single leg straight leg dead lifts	3kg medicine ball in hands	Blue-challenging fitness pad	2 x 45 each leg	40

Statistical Methods

The dependent variables were the Centre of pressure distribution (COP); Single leg triple hop for distance (SLTHD) and Normalised reach distance expressed as a percentage of subject's leg length (including anterior, posterior medial and posterior lateral distances). All data were analysed using a 2-way ANOVA with repeated measures, with one between-subjects factor (Treatment group; Combined Wobble board and Vibration vs. Wobble board vs. Control) and one within-subjects factor (Time; Pre- vs. Post-training). Once it has been determined that differences existed within time (pre- vs. post training) that also varied by group (identified by the group-by-time interaction), Bonferroni post hoc tests and pairwise multiple comparisons were used to determine which change values differed between treatment groups. An alpha level of $p<0.05$ was determined to be significant for all statistical comparisons (Raw data including confidence intervals can be found in appendix 10).

4.4 Results

Centre of pressure distribution and Single leg triple hop for distance results

There was a significant difference in COP distribution due to the main effect "time" [F (1, 30) = 57.99, p = 0.00] with a large effect size (partial eta squared = 0.659). Overall differences in COP due to the main effect "treatment group" were not significant [F (2, 30) = 2.57, p = 0.094]. However, a significant group-by-time interaction was observed [F (2, 30) = 6.74, p = 0.004] indicating that the changes in COP from pre- to post-intervention varied significantly between the three groups. This interaction effect is illustrated in Figure 4.3 which includes standard error scores. Post- hoc comparisons using Bonferroni test indicated that the changes in COP pre- to post-intervention of the control group differed significantly from the combined vibration and wobble group ($p < 0.001$); however the pre- to post intervention changes in COP of the wobble board group alone did not differ significantly from the control group ($p = 0.09$)(Table 4.2).

There was a significant difference in SLTH distance due to the main effect "time" [F (1, 30) = 15.02, p = 0.001] with a medium effect size (partial eta squared=0.334). Overall differences in SLTH distance due to the main effect "treatment group" were not significant [F (2, 30) = 1.13, p = 0.336]. However, a significant group-by-time interaction was observed [F (2, 30) = 10.52, p=0.001] indicating that the changes in SLTH distance from pre- to post-intervention varied significantly between the three groups. This interaction effect is illustrated in Figure 4.4 which includes standard error scores. Post- hoc comparisons using Bonferroni test indicated that the changes in SLTH distance pre- to post-intervention of the control group differed significantly from the combined vibration and wobble group ($p < 0.001$); however the pre- to post intervention changes in SLTH distance of the wobble board group alone did not differ significantly from the control group ($p = 1.00$) (Table 4.2).

Table 4.2 COP distribution (cm_2) and SLTH distance (cm) results (* Indicates significance P<.05). Bonferroni post hoc test was performed and results compared with control group.

Pairwise Comparisons COP (cm_2)			
Treatment group	**Treatment group**	**Mean Diff**	**Sig.**
1.Control	2.Vibration and Wobble	-1.13727	0.001*
	3. Wobble	-0.70091	0.09
Pairwise Comparisons SLTH distance (cm)			
Treatment group	**Treatment group**	**Mean Diff**	**Sig.**
1.Control	2.Vibration and Wobble	12.7273	0.001*
	3. Wobble	2.18182	1.00

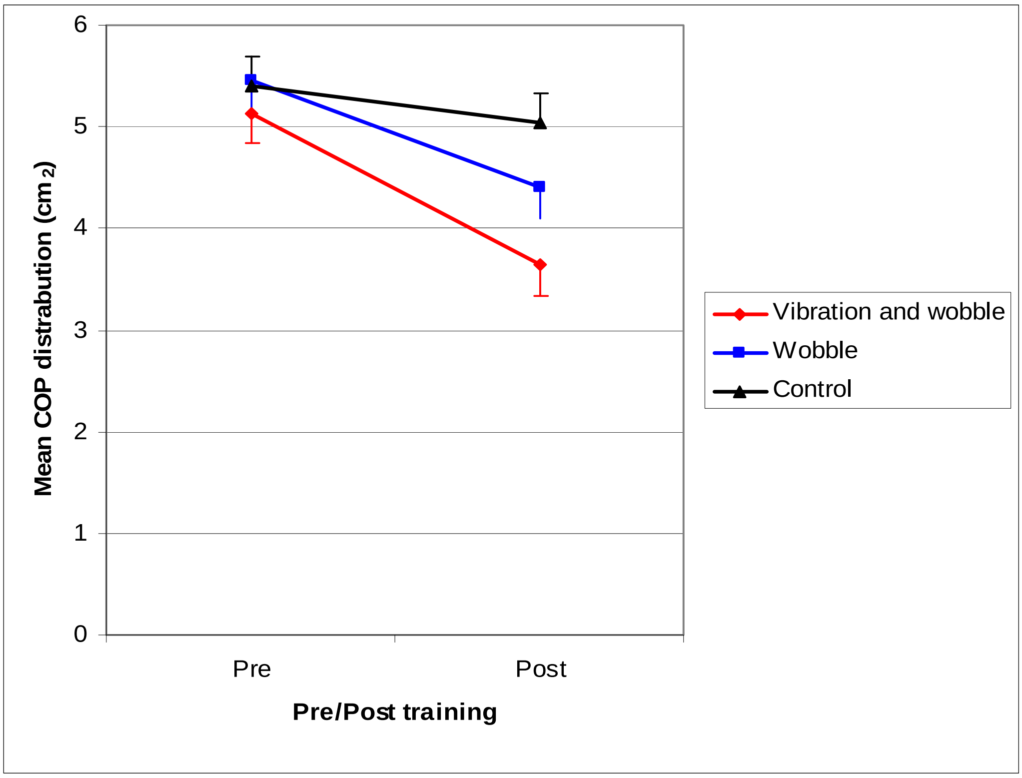

Figure 4.3 COP distributions between treatment groups over time. Error bars indicate standard error (Pre 0.3 cm_2 and Post 0.25cm_2).

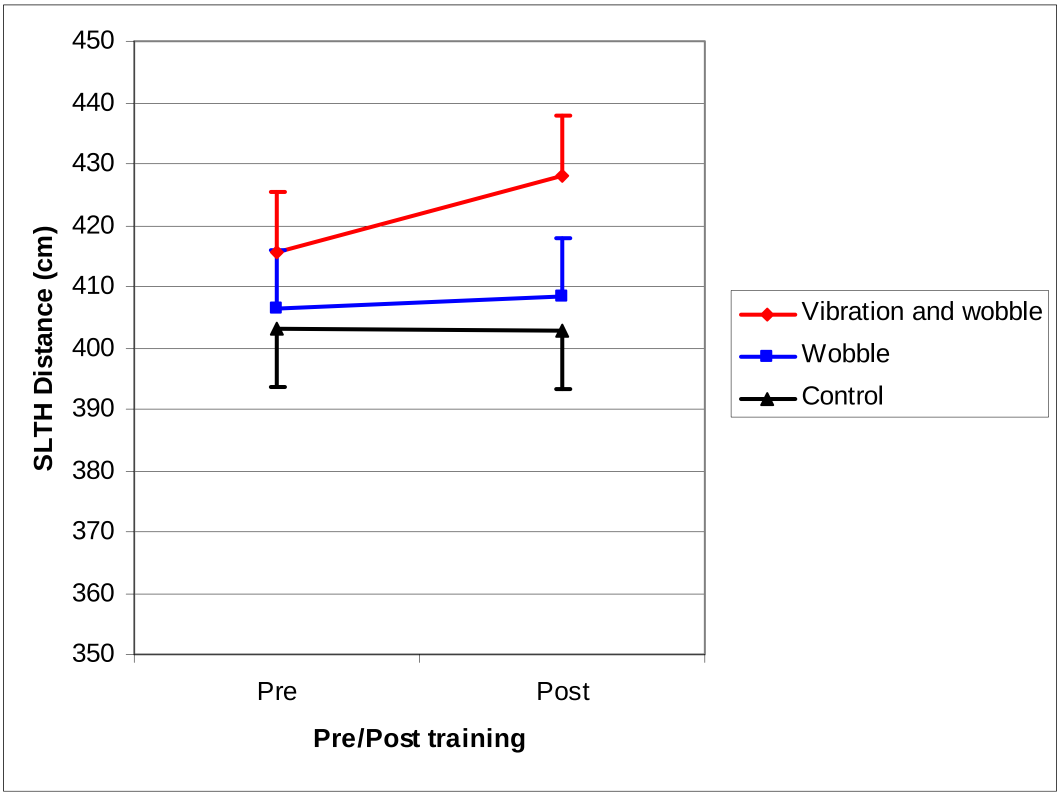

Figure 4.4 SLTH Distances between groups over time. Error bars indicate standard error (Pre 1.6 cm and Post 1.5cm).

Modified SEBT results

There was a significant difference in Anterior and Posterior lateral reach distances (%MAXD) distribution due to the main effect "time" [F (1, 30) = 6.97, p = 0.013] and [F (1, 30) = 11.99, p = 0.002] with a small effect size (partial eta squared=0.189 and 0.285). Overall differences in Anterior and Posterior lateral reach distances (%MAXD) due to the main effect "treatment group" were not significant [F (2, 30) = 0.62, p = 0.545] and [F (2,30) = 4.937, p = 0.140]. However, a significant group-by-time interaction was observed for anterior reach distance [F (2, 30) = 8.05, p = 0.002] and Posterior lateral reach distance [F (2,30) = 5.78, p = 0.008] indicating that the changes in Anterior and Posterior lateral reach distances from pre- to post-intervention varied significantly between the three groups. This interaction effect is illustrated in Figure 4.5 and 4.6 which includes standard error scores. Post- hoc comparisons using Bonferroni test indicated that the changes in Anterior and Posterior lateral reach distances pre- to post-intervention of the control group differed significantly from the combined vibration and wobble group (p < 0.001); however the pre- to post intervention changes in Anterior and Posterior lateral reach distances of the wobble board group alone did not differ significantly from the control group (Anterior: p = 0.11 and Posterior lateral: p = 0.78) (Table 4.3).

Table 4.3 Modified SEBT means and standard deviations of normalized reach distances (reach distance is cm/leg length in cm). Bonferroni post hoc test was performed and results compared with control group (* Indicates significance P<.05).

Pairwise Comparisons Anterior Reach Distance			
Treatment group	**Treatment group**	**Mean Diff**	**Sig.**
1.Control	2.Vibration and Wobble	5.181818	0.001*
	3. Wobble	2.818182	0.11
Pairwise Comparisons Posterior Medial Reach Distance			
Treatment group	**Treatment group**	**Mean Diff**	**Sig.**
1.Control	2.Vibration and Wobble	1.545455	0.26
	3. Wobble	0.727273	1.00
Pairwise Comparisons Posterior Lateral Reach Distance			
Treatment group	**Treatment group**	**Mean Diff**	**Sig.**
1.Control	2.Vibration and Wobble	3.727273	0.001*
	3. Wobble	1.272727	0.78

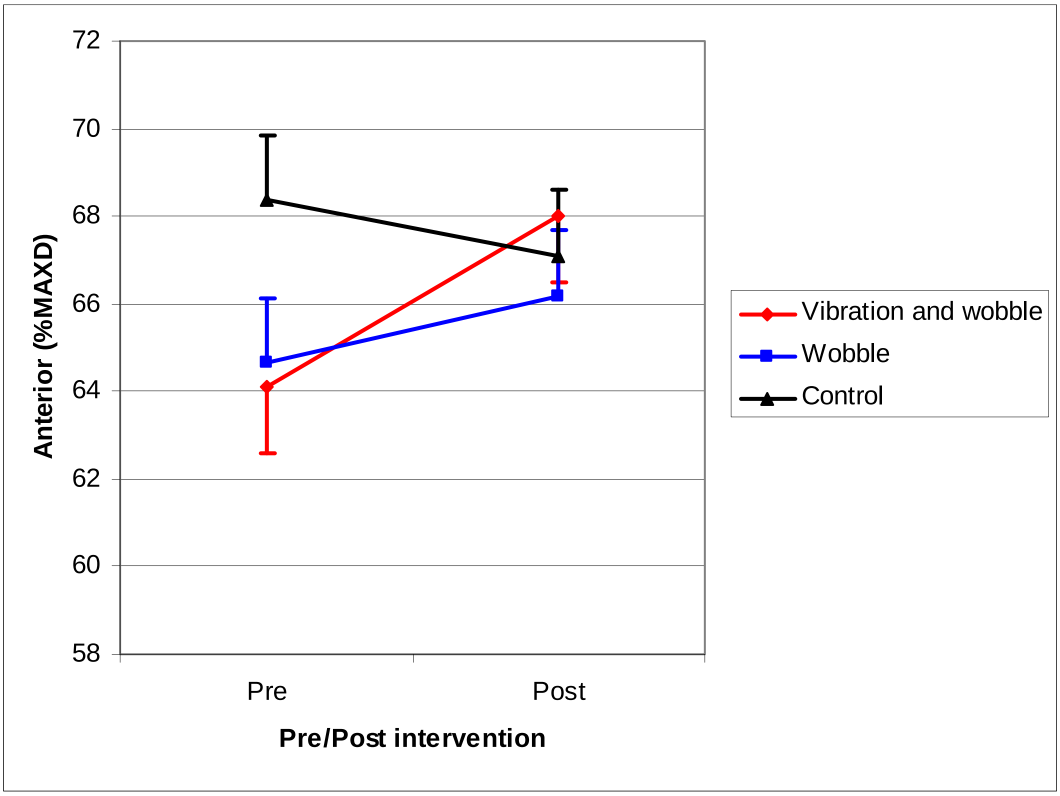

Figure 4.5 Anterior %MAXD reach distance between groups over time. Error bars indicate standard error (Pre 1.62 %MAXD and Post 1.55 %MAXD).

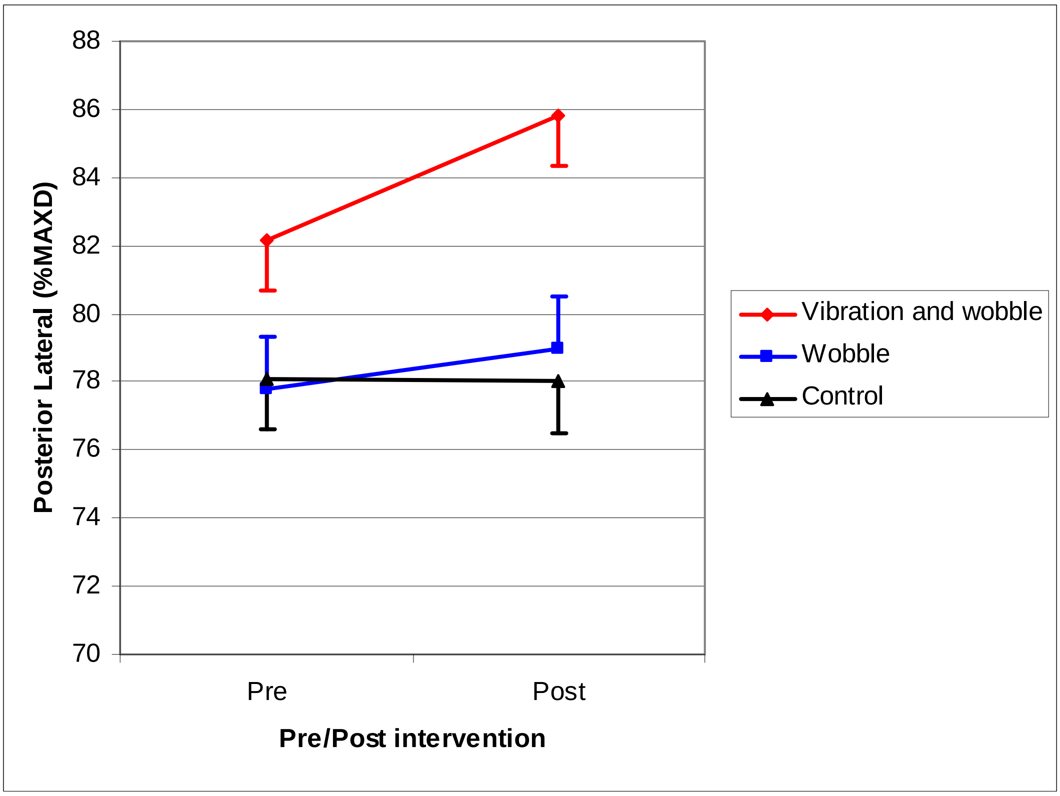

Figure 4.6 Posterior Lateral % MAXD reach distance between groups over time. Error bars indicate standard error (Pre 1.62 %MAXD and Post 1.55 %MAXD).

4.5 Discussion

When interpreting the results of the present study, it should be remembered that both Vibrosphere ™ and Wobble board groups did identical exercises on identical apparatus. With this in mind the results suggest that the addition of vibration provided extra benefit in SLTHD, static balance and Anterior/Posterior lateral reach distances. Vibration training has previously been suggested as a rehabilitation method amongst researchers; however none of these studies have looked at the treatment of FAI within athletic populations, concentrating more on fall prevention strategies amongst the elderly and ACL reconstruction patients (Torvinen *et al.* 2002a; Delecluse *et al.* 2003; Bogaerts *et al.* 2007; Kawanabe *et al.* 2007; Melnyk *et al.* 2008; Moezy *et al.* 2008; Rees *et al.* 2009; Trans *et al.* 2009). The use of a combination of a vibration device built into a wobble board has been investigated previously (Trans *et al.* 2009). Trans *et al.* (2009) used an eight week training cycle on a Vibrosphere ™ to assess strength and proprioception in elderly females suffering knee osteoarthritis. They found an improvement in proprioception; however no significant strength gains where reported. Although comparisons are difficult due to the participant pool, the reasoning behind differing effects in terms of strength increases may be due to the exercise routines being static knee flexion holds and the participants being a sedentary elderly population (Trans *et al.* 2009). Both studies however do conclude that the training device improves joint function over a relatively short period of time and number of sessions.

The static balance and SEBT improvements may also be associated with the benefits of vibration training. It has been well documented that the input of proprioceptive pathways (Ia, IIa, and IIb) are used in the production of isometric forceful contractions (Gandevia 2001). During WBVT, it has been reported these pathways are strongly stimulated (Delecluse *et al.* 2003). The vibratory stimulus is activating the sensory receptors that results in spontaneous muscle contraction. The increase in SLTH distances after six weeks of training, and thus after extensive sensory stimulation, might be as a result of a more efficient use of the positive proprioceptive feedback loop in the generation of intramuscular force production and isometric control (Delecluse *et al.* 2003). The present study suggests that the combination of wobble board training re-educating disrupted neuromuscular feedback and vibration targets not only the local muscles such as tibialis anterior, peroneus longus and gastrocnemius (Soderberg *et al.* 1991), but possibly core muscle groups.

The more challenging exercises undertaken by the athlete may have improved core activation and control which has been linked with improved balance and postural control (Leetun *et al.* 2004; McKeon *et al.* 2008; Behm *et al.* 2010; Kaji *et al.* 2010), thus this could explain the improvement seen in static balance and SEBT. This theory has also been supported by previous research which indicates improvements in SEBT may be achieved through increased abdominal activation (Gage and Hopkins 2008). With contemporary research highlighting the importance of rehabilitation within unstable ankle populations concentrating on a whole body system of work not just the peripheral site of the injury (Hass *et al.* 2010), such as balance/vibrations stimulation, mediated by a progressive set of exercises. However this research acknowledges that any such assumptions from the present results are tenuous but would encourage further investigation into the area.

Vibration training has been well documented as a training method for improving neuromuscular properties of skeletal muscle, such as strength and power indices (Bosco *et al.* 1999b; Cardinale and Bosco 2003; Delecluse *et al.* 2003; Luo *et al.* 2005; Paradisis and Zacharogiannis 2007; Maran and Rhea 2010). Such structural changes are not only mediated by intramuscular factors but also by neural adaptation, allowing a more co-ordinated and forceful activation during different permutations of movement (Torvinen *et al.* 2002a). This knowledge of vibration training and neuromuscular adaptation may help to understand the above findings amongst the Vibrosphere ™ training group, particularly amongst the SLTHD, however as with previous studies (Torvinen *et al.* 2002a), the absence of EMG profiling or muscle biopsies means any such conclusion is difficult. However on the basis of the evidence set forth above it could be assumed that such adaptations have occurred, the exact reasoning behind this is beyond the findings of this study.

4.6 Conclusion

Six weeks progressive wobble board and vibration training (Vibrosphere ^{TM}) significantly improved static balance, as measured by mean COP excursion, dynamic balance, as assessed by modified SEBT and SLTHD in comparison to wobble board training alone. Combined wobble board and vibration training would appear to be beneficial to football players suffering FAI. However this study acknowledges these are not sole predicators of injury and future longitudinal studies are needed to assess how long these positive results continue and whether this information correlates with re-injury risk. This is particularly important for footballers as by assessing if the intervention itself has reduced injury occurrence, we can begin to reduce one of the main contributing factors to injury risk in football; That is a previous/or recurrent history of ankle injury (Arnason *et al.* 2004). More research is needed to assess actual muscle contribution during the combined wobble board and vibration training and the effect this may have on postural control and balance.

CHAPTER FIVE –SUMMARY

5.1 Summary

The primary goal of the present research was to determine whether vibration training is effective in improving balance and strength indices in functionally unstable ankles. **Study 1** indicated WBVT improved static balance and SEBT scores amongst dancers exhibiting ankle instability but did not affect peroneus longus muscle fatigue. The application of vibration was then developed to see how effective the stimulus was when combined with a wobble board and when wobble board training was done on its own. With the introduction of the Vibrosphere ™ this provided the perfect opportunity to test this theory as the two methods were incorporated and therefore comparisons of both methods could not be associated with different pieces of equipment but with the addition/absence of vibration stimulus. **Study 2** has indicated that combined vibration and wobble board training (Vibrosphere ™) improved static balance, modified SEBT scores and SLTHD amongst footballers suffering FAI compared to wobble board training alone.

While several authors (Bosco *et al.* 1999a; Bosco *et al.* 1999b; Mester *et al.* 2006; Nordlund and Thorstensson 2007; Rehn *et al.* 2007; Savelberg *et al.* 2007) have investigated the effect of vibration training on strength and power indices as an alternative to conventional resistance exercise. Only more recently has the focus of vibration training been on improving balance and muscle function in elderly populations due to their increase fall risk (Bogaerts *et al.* 2007; Kawanabe *et al.* 2007; Melnyk *et al.* 2008; Moezy *et al.* 2008; Rees *et al.* 2009; Trans *et al.* 2009) . This evidence seems to suggest that vibration training has a beneficial effect of balance and muscle function in this population.

This led to the current research investigating other populations who suffer poor balance and muscle function such as FAI and whether any improvements from such exposure could be identified. Previous to the current research however, this had yet to be ascertained by any researchers in young athletic populations still competing in their competitive sports. Although the benefits had been reported in older populations, it seems from the current research that such benefits may be transferable to younger populations regardless of differences in muscle fatigue, maximum strength and balance indices (Wiksten *et al.* 1996; Russ *et al.* 2008) or resistance training background, which has been identified in the past as leaving the opportunity for significant improvements being limited compared to sedentary populations (Wahl and Behm 2008).

The literature reviewed suggests FAI is presented by poor balance and strength deficits, increasing an individual's risk of recurrent episodes of ankle trauma (Hertel 2000). Konradsen (2002b) presents a pathogenetic model which proposes a direct cause-effect relationship between proprioceptive deficits in the ankle of functionally unstable subjects, and increased risk of unprovoked ankle distortion injuries. Treatment for such a condition ranges from strength training (Kaminski *et al.* 2003; Powers *et al.* 2004; Palmieri-Smith *et al.* 2009); balance/proprioception (Waddington *et al.* 1999; Verhagen *et al.* 2004; Clark and Burden 2005) and increasingly novel computerised training games using wobble boards (Fitzgerald *et al.* 2010) with varying success. As yet no research has investigated the effect of vibration training on functional ankle instability, it was the current researches hypothesise that vibration will improve balance and muscle function in individuals suffering functional ankle instability. In order to test these hypothesis two studies were carried out, firstly to identify if at all there was a positive effect using vibration training and secondly directly comparing vibration training with a more classical rehabilitation method.

Chapter 3 "*The effects of 6 weeks whole body vibration training on balance and muscle fatigue in recreational dancers with functionally unstable ankles*" used data from 38 female recreational dancers randomly assigned to vibration and control groups to determine the effect of vibration on single leg static balance, star excursion balance test (SEBT) and peroneus longus fatigue. The main findings of the study indicate that six weeks of WBVT on a stable vibration platform significantly improved single leg static balance and SEBT scores compared to controls. There was no significant difference in peroneus longus fatigue. Interestingly although there was an improvement in static and dynamic balance, there was no alteration in muscle fatigue properties indicating that the results where not due to structural changes but maybe re-education of higher systems such as joint and ligmentous mechanoreceptors. It was also interesting to note, although not significant, there was a improvement in SEBT scores among the control group, leading to support the suggesting that it may also be a good rehabilitation intervention in itself (Brumitt 2008) or that there was a learned effect in testing/re-testing. Also single leg balance scores were significantly lower then in previous research (Arnold *et al.* 2009; Ross *et al.* 2009b), this seems to support the theory that participants that engage in activities which stress balance/aesthetics (gymnastic/dance) will exhibit naturally better balance (Aydin *et al.* 2002).

These results support the hypothesis that WBVT improves balance in participants reporting FAI. The initial study adopted in chapter 3 provides a six week training plan of WBVT never used before as well as a combination of static balance and SEBT scores for dance population reporting FAI previously never published before. Also the study highlights the difficulty at assessing muscular fatigue and the need for a more dance specific challenging exercise to promote changes in mean power frequency as this was not challenging enough.

The original hypothesis of the study was to assess the effectiveness of vibration training on improving balance and muscle function in functionally unstable ankles. However, following the initial positive results the real contribution of the vibration training was yet to be examined, as well as a comparison with more traditional rehabilitation methods. This is key in injury prevention research, as to often positive results are lauded, however it should be noted vibration devices are expensive and does the extra expense provide a more significant improvement then a cheaper classical alternative. Also the importance of balance training is widely accepted by clinician as the ankles possess a large amount of mechanoreceptors which after injury require retraining (Michelson and Hutchins 1995; Javed *et al.* 1999; Ashton-Miller *et al.* 2001).

This leads to Chapter 4 "*An investigation into the effect of 6 weeks combined vibration and wobble board training on balance and dynamic stability in footballers with functional ankle instability*" which compared combined wobble board and vibrations training with wobble board alone. This study also examined for the first time a new piece of rehabilitation equipment (Vibrosphere ^{TM}) and provided original contribution of knowledge in terms of devising a six week rehabilitation programme using this equipment. Despite wishing to maintain the tests used in previous research we had to adapt the testing to suit both the players timetable and medical staff. Although single leg balance was the same, the SEBT was adapted following previous research suggesting a modified SEBT is more practical for large teams. The opportunity to assess muscle function using EMG was not appropriate so a functional test of strength and muscle function in single leg triple hop for distance was used. Thirty-three semi-professional football players where screened again using the CAIT and assessed by club physiotherapist before being randomly assigned to one of three treatment groups (Vibrosphere ™, Wobble board and control). Both training groups completed identical exercise so that any improvement could not be associated with different equipment/training. The purpose of the balance training program was twofold, firstly to develop a regimen to improve balance and secondly, to construct a program of exercises that would be easily implemented in pre-season training with the time constraint imposed. At the end of the six weeks all participants were retested by the same investigator to prevent any internal validity issues. While both intervention groups score increased across all testing variables, the increase in pre/post scores was significantly greater in the group that underwent training combined vibration and wobble board (Vibrosphere ™), suggesting that the added vibration stimulus enhanced the balance and muscle function of footballers suffering functional ankle instability. This study also supported the hypothesis that the vibration contribution clearly adds a positive effect to balance and muscle function and the direct reasoning behind this needs further investigation before any definitive statements can be made.

CHAPTER SIX-LIMITATIONS OF RESEARCH

There are a few limitations to the present study. Firstly, the subjects in our study were classified as having unilateral instability. Instability status and inclusion in the study were based on the subjects' self-reported history of ankle injury. Self-reported history is not always reliable. However, based on the results of the CAIT, investigators reported significantly impaired function in their unstable ankle versus their healthy ankle. The research does accept however due to a lack of previous medical data, actual improvements could not be compared to pre injury base line data for the affected limb.

Therefore, it was felt that the subjects injured ankle was correctly classified as unstable. Perhaps the most important challenge proposed to researchers concerns the actual presence of functional ankle instability in subjects recruited for research investigations. No universally accepted definition of functional ankle instability exists (Kaminski and Hartsell 2002), nor is there any quantification of what constitutes functional ankle instability. Konradsen and Magnusson (2000) suggest the lack of a consistent set criterion for functional ankle instability may not be providing researchers with the true subject pool needed to study the phenomenon further. Until the research community settles on a standardised set of criteria for classifying functional ankle instability, difficulties in trying to compare and contrast research findings will persist. The CAIT has been reported as a good tool for identifying ankle instability (Hiller *et al.* 2006; De Noronha *et al.* 2008), however its sensitivity for tracking improvement in stability over a relatively short intervention has been questioned (Sesma *et al.* 2008), as such its follow up use was omitted.

Ankle instability after an ankle sprain shows for instance in balance deficits, joint position sense deficits, delayed peroneal muscle reaction time, strength deficits, and a decreased dorsiflexion range of motion (Hertel 2000). Although these parameters are interrelated to a large extent, it is not unlikely that the magnitude of the deficits varies among individuals. Whereas one individual has a great balance deficit after an ankle sprain, another individual might have less balance problems and more joint position sense deficits (Verhagen *et al.* 2005). With the absence of a consultant orthopaedic surgeon and expensive MRI technology, the contribution of mechanical and neurological differences between individuals was not identified and this may well be the reason of the various findings between both studies as the tests used suited some more then others.

Konradsen (2002b) points out that one of the entities behind maintenance of functional ankle stability is the individual's ability to avoid situations where the foot/ankle complex is forced into excessive inversion motion prior to loading. The SEBT test although classed as a dynamic balance test (Kinzey and Armstrong 1998; Hertel *et al.* 2000; Gribble *et al.* 2007) still lacks in terms of pushing the ankle joint to a position of increased injury risk, for example inverted plantar flexion (Wright *et al.* 2000). Although the research did look to introduce this concept in the second study with basic single leg triple hop for distance, Single leg time to stabilisation (Ross *et al.* 2005) should have been used. Due to transportation issues with the force platform this was not possible.

During the first study we did not assess mechanical instability with taler tilt test and anterior drawer test. Although this has also been excluded in other studies due to the subjective nature of the test and optimal pressure needed to be applied (Tohyama *et al.* 2003; Hubbard *et al.* 2005). We did include it in the second study as we had the medical staff present to conduct the test. Ideally we should have done this in study one to totally eliminate any mechanical instability issues. Secondly, we did not assess for congenital laxity of other joints, we simply screened the participant for previous injury to other joints. This may have missed other impairments in the knee and hip, contributing to the results obtained (Hubbard *et al.* 2005).

CAHAPTER SEVEN-FUTURE RESEARCH

Further research is recommended arising from the present work. The present results may be explained by a combination of uneven surface training and vibration training having an increased neuromuscular response during training cycles. Much of the research on vibration training and balance has been done on elderly populations who have significant strength deficits. FAI sufferers have also reported similar strength deficits and this may be why both groups exhibit positive effects, as these deficits allow room for significant improvements. However to assess the true contribution of the vibration, EMG needs to be examined during the actual training exercises. This would also allow direct comparison of stable and unstable vibration devices and whether there are added benefits with either one. To do this accurately however, is difficult and firstly research needs to examine the use of accelerometers and EMG in combination. As during vibration the EMG signal being picked up is corrupted by the mechanical resonance of the muscle itself and not the contraction of the muscle, causing a overestimation of effect (Fratini *et al.* 2009).

The SEBT needs further examination on its effectiveness across different populations. Comparisons between both studies was difficult, although both scored similar CAIT scores for instability, the SEBT score were not comparable. Dorsiflexion is key when performing the star excursion test in particular the posterior planes of motion (Gribble *et al.* 2007). This could be key in explaining differences between dancers and footballers as footballers have notoriously limited dorsiflexion due to overuse injuries and limited flexibility. There may be a need for a re-examination of this test amongst athletes within sports with an inherently balance/aesthetic based discipline.

Moreover, most rehabilitation training programs and/or exercise intervention studies have only examined the improvements before and after training; therefore, a study design with a follow- up test is strongly needed to demonstrate that the sustained effects of vibration training is more clinically relevant. As many adults still have problems up to a year after acute ankle injury which may lead to more degenerative conditions in later life if not treated (Margo 2008). Verhagen and Van Mechelen (2010) advocate an intervention mapping protocol (IM). The structure of such a study would be; 1) the definition of programme objectives, based on analyses of the health problem; (2) the selection of adequate methods to realise change; (3) the design of the intervention programme, as well as the selection, pretesting and production of the intervention materials; (4) the development of a plan for the implementation; and (5) evaluation. An important feature of the IM protocol is a continuous and consistent dialogue. This may seem very labour intensive but is an important step if we wish to start implementing acceptable vibration interventions to other populations and help prevent re-injury.

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